The development and evaluation of a structured conditioning programme on physiological performance under conditions of high +Gz

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The Development and Evaluation of a Structured Conditioning Programme on Physiological Performance Under Conditions of High +Gz

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Submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy

Declaration

This dissertation is the result of my own work. It has not been previously submitted, in part or whole, to any university of institution for any degree, diploma, or other qualification.

In accordance with the Faculty of Life Sciences and Medicine guidelines this thesis does not exceed 100,000 words.

Signed:____

Date:____

Ellen Slungaard MSc.

Abstract

There remains concern over the ability of aviators to tolerate the considerable +Gz stressors of the modern high performance aviation environment. The aim of this thesis was to further understand the present status of +Gz related incidents in the Royal Air Force (RAF), to design and construct validate a physical conditioning programme, then test its efficacy on performance under high +Gz.

A survey was conducted asking 2351 aircrew (1878 pilots, 473 weapon systems operators) to describe details of G-induced loss of consciousness (G-LOC) and almost loss of consciousness (A-LOC) events. The results revealed that the prevalence of reported +Gz related incidents in the RAF remains a hazard to all aircrew with 14.8% reporting a G-LOC and 32.2% reporting an A-LOC event at some point in their flying career. Student aircrew reported a higher incidence of both events, presumably due to their relative inexperience in both +Gz awareness and ability to perform an effective anti-G straining manoeuvre (AGSM).

An Aircrew Conditioning Programme (ACP) was developed which incorporated exercises designed to enhance performance through improvements in the ability to repeatedly perform an AGSM and subjected to construct validity by a panel of experts. The ACP demonstrated excellent content validity for the individual exercise sessions and for the overall programme in terms of relevance and simplicity for delivery to the aircrew population.

A controlled trial was undertaken into order to test the efficacy of the ACP (n=16 ACP, and 19 controls) took part in a 12 week programme after which performance on the man carrying centrifuge under high +Gz was assessed. The ACP did not negatively affect relaxed or straining +Gz-level tolerance (SGT). However, during the +5.5 Gz SGT step a lower physiological strain was indicated in the ACP group by a lower heart rate for the equivalent load (pre 146.0 ± 4.4, post 136.9 ± 5.6 beats.min^{-1}) compared with the Control group (pre 148.0 ± 3.2, post 153.1 ± 3.3 beats.min^{-1}), while mean arterial blood pressure was unchanged. During the simulated air combat manoeuvre runs the number of +7 Gz peaks completed by each subject (maximum of 16) had a tendency to increase in the ACP group only (pre 14.0 ± 1.2, post 15.4 ± 0.4) whereas the control group had a tendency to reduce (pre 14.0 ± 0.9, post 13.6 ± 1.1).

Overall the data in this thesis suggest that G-LOC remains a significant issue among fast jet air crew and that the use of an ACP may help to ameliorate physiological challenges faced under high Gz.

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Publications Resulting from This Work

Journal papers:

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Conference proceedings:

Slungaard E, Green NDC, Pollock RD, Stevenson AT, Newham DJ, Harridge SDR. The effects of an Aircrew Conditioning Programme on performance during high +Gz. *Aerosp Med Hum Perform.* 2018; **89**: 124.

Slungaard E, Green NDC, Newham DJ, Harridge SDR. Content validity of the Royal Air Force Aircrew Conditioning Programme. *Proceedings of the 63rd International Congress of Aviation and Space Medicine.* 2015; **P93**.

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List of Abbreviations and Acronyms

+Gz	Acceleration, the inertial force of which is directed head-to-foot
ACM	Air combat manoeuvre
ACP	Aircrew Conditioning Programme
AGSM	Anti-G straining manoeuvre
AGT	Anti-G trouser
A-LOC	Almost loss of consciousness
ANOVA	Analysis of variance
BFJT	Basic Fast-Jet Training
BFM	Basic fighter manoeuvre
BP	Arterial blood pressure
beats.min^{-1}	Beats per minute
Ca2+	Calcium
CAM	Centre of Aviation Medicine
CO_2	Carbon dioxide
DBP	Diastolic blood pressure
ECG	Electrocardiogram
EFT	Elementary Flying Training
EMG	Electromyography
ESA	European Space Agency
FACT	Fighter Aircrew Conditioning Test
$FeCO_2$	Expired fraction of carbon dioxide
FeO_2	Expired fraction of oxygen
$FiCO_2$	Inspired fraction of carbon dioxide
FiO_2	Inspired fraction of oxygen
FT	Flying Training
g	Gravity
G-LOC	G-induced loss of consciousness
GOR	Gradual onset rate acceleration exposure
GRIM	G-Risk Indicator Management
HR	Heart rate
Hz	Hertz
I-CVI	Item content validity index
IFF	Introduction to Flying Fundamentals
ISS	International Space Station

LBNP	Lower body negative pressure
LED	Light emitting diode
MAP	Mean arterial blood pressure
mmHg	Millimetres of mercury
MOD	Ministry of Defence
MVIC	Maximal voluntary isometric contraction
PTI	Physical Training Instructor
RAF	Royal Air Force
RAAF	Royal Australian Air Force
RGT	Relaxed +Gz tolerance
RMS	Root mean square
RN	Royal Navy
ROR	Rapid onset rate acceleration exposure
SACM	Simulated air combat manoeuvre
SBP	Systolic blood pressure
S-CVI	Scale-level content validity index
SE	Standard error of the mean
SGT	Straining +Gz-level tolerance
USAF	United States Air Force
VM	Valsalva manoeuvre
μG	Microgravity

Glossary of Terms

ACM	Air combat manoeuvre	The art of manoeuvring a combat aircraft in order to attain a position from which an attack can be made on another aircraft, which relies on offensive and defensive basic fighter manoeuvres.
AGSM	Anti-G straining manoeuvre	A learned technique consisting of a co-ordinated, sustained lower body and abdominal muscle contraction combined with a cyclic forced exhalation maintained for 3-4 s against a partially or completely closed glottis, interspaced with rapid inhalations.
AGT	Anti-G trouser	A trouser-like garment designed to raise acceleration tolerance by applying pressure to the lower body.
BFJT	Basic Fast-Jet Training	Initial fast-jet training completed by aircrew who have completed EFT and deemed suitable for fast-jet flying.
BFM	Basic fighter manoeuvre	Tactical movements performed by combat aircraft during air combat manoeuvring to gain a positional advantage over an opponent.
EFT	Elementary Flying Training	Initial flying training for all aircrew in the RAF and RN.
FACT	Fighter Aircrew Conditioning Test	A physical conditioning test consisting of 8 exercise events divided into strength and endurance categories.
GOR	Gradual onset rate acceleration exposure	A rate of acceleration of 0.1 $G.s^{-1}$ which allows the arterial baroreceptor reflex to be fully activated in order to preserve head-level BP.
GRIM	G-Risk Indicator Management	A program developed by the Unites States Air Force to enhance combat capability and safety by identifying aircrew with poor +Gz performance using the FACT.
+Gz-duration		The tolerance limit an individual reaches a recognisable level of subjective fatigue such as limit of volitional tolerance or visual loss.
+Gz-level tolerance		The highest +Gz load attained without G-LOC.
I-CVI	Item content validity index	Calculated for each item (each individual exercise session) as the number of experts giving a rating of acceptable (score 3 or 4), divided by the total number of experts, based on the ratings of relevance and simplicity.
RGT	Relaxed +Gz tolerance	The +Gz-level tolerance limit attained with the individual remaining relaxed.
ROR	Rapid onset rate acceleration exposure	A rate of acceleration of 1.0 $G.s^{-1}$ or greater.
SACM	Simulated Air Combat Manoeuvre	A profile used in a man-carrying centrifuge to examine +Gz duration involving alternating +Gz plateaus of +5 Gz for 15 s and +7 Gz for 5 s to a visual or fatigue end-point, or measurement of physiological strain.
S-CVI	Scale-level content validity index	Calculated as the average proportion of items rated as 3 or 4 across the various experts for relevance and simplicity using the averaging approach (S-CVI/Ave).
SGT	Straining +Gz level tolerance	The +Gz-level tolerance limit attained with the individual straining as when performing the AGSM or tensing only the muscles of the lower limb and abdominals.
VM	Valsalva manoeuvre	Forced exhalation against a closed airway.

Chapter 1 Introduction

Concern over the ability of aviators to tolerate the considerable +Gz stressors of the modern high-performance aviation environment has grown in recent years. This ability is affected by physical countermeasures such as an effective anti-G straining manoeuvre (AGSM) and being able to move and look out of the cockpit during periods of high +Gz. Physical conditioning may also be effective yet few studies have investigated this rigorously (Bateman et al. 2006).

There are direct and indirect consequences of +Gz stress. Direct consequences include symptoms such as loss of peripheral visual fields, visual greyout or blackout, and G-induced loss of consciousness (G-LOC) (Bateman et al. 2006). Indirect consequences include fatigue and subsequent loss of performance, and strain injuries, specifically to the neck. Both of these direct and indirect consequences may have a broader effect on pilot performance operationally, affecting the capacity of the aviator to manage +Gz stress and complete the mission effectively (Bateman et al. 2006).

The physical forces encountered during +Gz exposure may lead to fatigue and injury. Most injuries reported among fighter pilots are described as strain of the neck muscles, with occasional neck pain and stiffness, related to frequent exposure to high +Gz forces in high performance jet aircraft (Ang et al. 2005). Physical conditioning programmes may reduce these injuries, which would in turn enhance pilot performance. To date the Royal Air Force (RAF) has no specific structured strategy to deal with this issue.

The overarching aim of the work presented in this thesis is to further understand the present status of +Gz related incidents in the RAF, design, construct validate and test the efficacy of physical conditioning programme on performance under high +Gz.

Chapter 2 Structure of the Thesis

The ability to operate in a high +Gz environment is physically demanding and can lead to fatigue and subsequent risk of injury or loss of consciousness, with possible loss of aircraft and/or life. Before investigating the extent of G-LOC and A-LOC in the RAF (Chapter 4), an extensive review of the literature will establish the relevant scientific background (Chapter 3). The mechanics of acceleration will be briefly discussed (section 3.1), followed by the cardiovascular effects of +Gz acceleration (section 3.2). The methods used to protect individuals against the effects of high +Gz are also discussed (section 3.3). The subsequent sections describe conditioning programmes (section 3.4) and G-LOC (section 3.5).

In Chapter 5, an exercise programme (Aircrew Conditioning Programme - ACP) will be described in detail with rationale and evidence provided for each element. It will also undergo content validation by a panel of experts. Chapter 6 is the main experimental chapter which will investigate whether the ACP enhances aircrew performance in a high +Gz environment simulated on a man-rated centrifuge. Specifically; i) is relaxed +Gz-level tolerance reduced by the ACP? ii) is straining +Gz-level tolerance increased by the ACP? and iii) does the ACP increase +Gz-duration tolerance to repeated high sustained +Gz? The collective findings and conclusions are presented in the final chapter of this thesis (Chapter 7).

Chapter 3 Background and Literature Review

3.1 Acceleration Mechanics

Prior to describing the physiological effects of acceleration, it is first necessary to describe the forces encountered in flight. Acceleration describes a change in velocity of an object, defined as the rate of change of velocity and is a vector quantity having magnitude and direction (Green 2006a). Acceleration is classified according to duration and in this thesis only those of 'long duration' lasting for periods of more than two seconds are considered.

Applied acceleration in aviation is commonly expressed in terms relative to the normal acceleration due to gravity and is termed 'G'. Acceleration due to gravity is a physical constant (the gravitational constant) and is indicated by the symbol 'g' with the value 9.81 m.s^{-2}. The G value of an applied acceleration is given as:

Equation 1

$$G = \frac{applied\ acceleration}{g}$$

Acceleration can occur through a change in direction without a change in speed and is described as radial acceleration. Radial acceleration is most common in high performance aircraft, particularly when performing a loop or turning in a circle. Newton's first law of motion states that "unless acted upon by a force, a body at rest will remain at rest and a body in motion will move a constant speed in a straight line". Therefore, a body constrained to move along a circular path will have the tendency to continue on a straight line that forms a tangent to the circular path. The object is prevented from moving tangentially by a force that pulls it away from the straight line towards the centre of the circle, known as centripetal acceleration as it acts towards the centre of the circle.

Newton's third law states that to every action there is an equal and opposite reaction, which means that an equal force (centrifugal force) must act in an opposite direction (Figure 3.1). It is this centrifugal force which is experienced by aircrew in high performance aircraft and its magnitude is determined by the velocity of the aircraft and the radius of the turn:

Equation 2

$$a = \frac{v^2}{r}$$

Where a is the centripetal acceleration, v the circumferential velocity and r the radius of the circular path.

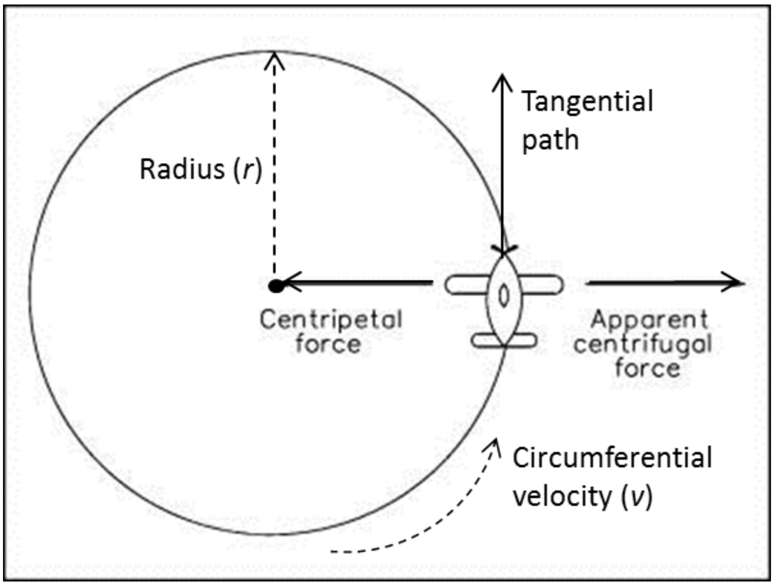

Figure 3.1 The relationship between centripetal and centrifugal force with the tangential component of circular motion indicated.

In aerospace medicine, the direction of force applied to an individual is defined in terms of inertial reaction, rather than applied accelerative force. It is described by the use of a three-axis co-ordinate system (*x, y, z*), whereby the vertical axis (*z*) is the long spinal axis of the body. A prefix is added to indicate the direction in which the forces are applied

(Figure 3.2). This terminology relates to the person and their orientation, rather than the forces acting on the aircraft. For example, in the *z* axis an inertial force acting from head-to-foot is positive (+) and foot-to-head negative (-). This thesis is solely concerned with the effects of +Gz acceleration.

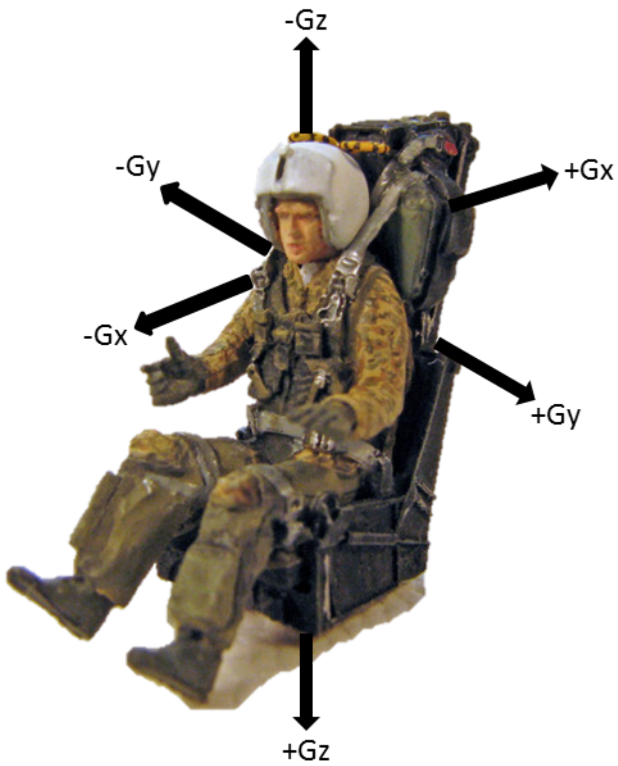

Figure 3.2 Standard aeromedical terminology for describing the direction of acceleration and inertial forces. The vector arrows indicate the direction of the resultant inertial forces.

3.2 Cardiovascular Effects of +Gz Acceleration

Exposure to +Gz acceleration has a profound effect on the cardiovascular system resulting in immediate changes in the distribution of pressure in the arterial and venous systems. This section will review the evidence for the effect of +Gz on the cardiovascular system.

3.2.1 Hydrostatic Pressure

The cardiovascular changes under +Gz acceleration result from an increased hydrostatic gradient present in the arterial and venous systems as +Gz acceleration increases. The hydrostatic pressure resulting from exposure of a column of fluid to acceleration is given by:

Equation 3

$$p = h\rho g$$

Where p is the pressure exerted by a column of fluid, h is the height of that column, ρ is the density of the fluid and g is the acceleration to which it is exposed. As g is increased, so the pressure exerted by the column of fluid is increased.

In a seated individual the column of blood in the arterial system between the heart and the head in most adults equates to ~ 30 cm in height. If the density of blood is assumed to be 1.06 $g.ml^{-1}$ and g is assumed to be 9.81 $m.s^{-2}$, then the head level pressure drop at +1 Gz can be calculated as approximately 22 mmHg using Equation 3. At +5 Gz, a hydrostatic pressure drop of 110 mmHg (5 x 22 mmHg) will occur. If heart-level systolic blood pressure (BP) is assumed to be 110 mmHg, and in the absence of any cardiovascular reflexes, it can be assumed that most individuals will have little or no head-level BP at this acceleration level (Green 2006a). Therefore, to maintain adequate arterial pressure in the brain, arterial pressure at heart level must increase to overcome the exaggerated hydrostatic drop along the arteries from the heart to the head (Kolegard et al. 2013).

3.2.2 Venous Pooling

The hydrostatic model assumes that the vasculature of the individual is a set of inelastic tubes. In reality, it is elastic and the pressure changes will result in a redistribution of blood volume mainly towards the lower limbs. When moving from a supine to an erect posture between 500-1000 ml of central blood volume is almost immediately redistributed to predominantly the lower limb veins with 80 % in the upper leg (Smit et al. 1999) as a result of their marked compliance (Gelman 2008). When exposed to +5 Gz acceleration for 15 s, 60 – 100 ml of blood is pooled in the lower limbs of a seated individual, but it should be noted that the circulation is already compromised by gravity due to moving from a supine position (Green 2006a).

3.2.3 Baroreceptor Reflex

The reduction in effective circulating volume and BP changes caused by increasing +Gz acceleration produce a reflex response involving the arterial baroreceptors located in the carotid sinus and aortic arch. Heart rate (HR) is increased by reduced vagal inhibition and vasoconstriction occurs, increasing peripheral resistance. This baroreceptor reflex provides a compensatory mechanism to preserve head-level BP, and is characterised by a recovery 6-12 s after the onset of acceleration exposure (Wood, Sturm 1989).

Exposure to gradual onset rate +Gz acceleration results in an increase in HR by between 8-12 beats.min.G^{-1} (Forster 1994, Forster & Whinnery 1988, Scott et al. 2013), yet in contrast, rapid rates of +Gz acceleration result in much lower increases in HR (4.8 G.s^{-1} ; 1-2 beats.min.G^{-1}) (Forster & Whinnery 1988). The capacity and maintained speed of the baroreceptor reflex during orthostatic stress has been associated with a higher relaxed +Gz tolerance on slow onset rates (0.1 G.s^{-1}) (Sundblad et al. 2016). Therefore, it would appear that at high acceleration onset rates the cardiac baroreceptor response is unable to maintain head-level BP.

Baroreceptor sensitivity may be modified through repeated exposure to +Gz acceleration with a ‘sharpening’ of the reflex, acting as a protective response (Stevenson et al. 2014). It is characterised by adjustments in the tone of vessels below the heart, limiting the fall in heart-level BP and changes in the cardiovascular system resulting in tachycardia and increased peripheral vasoconstriction (Scott et al. 2013).

3.3 Protection against the Effects of +Gz

As previously discussed an inability to counter the effects of +Gz acceleration beyond +5 Gz in a relaxed individual will result in G-induced loss of consciousness (G-LOC). High performance aircraft are capable of sustaining acceleration as high as +9 Gz which has resulted in a number of countermeasures being developed to increase an individual's +Gz tolerance. A description of the two main countermeasures used in this study will now be discussed.

3.3.1 Anti-G Trousers

Anti-G trousers (AGT) are a trouser-like garment designed to raise acceleration tolerance by applying pressure to the lower body. They consist of an outer restraining layer made of non-stretch material containing 5 interconnecting non-circumferential bladders. The bladders and their outer restraining coverings fit over the abdomen and wrap around the thighs and calves, covering approximately 40 % of the body below the umbilicus. The suit inflates rapidly at the start of an exposure to a uniform pressure throughout, through a flexible hose connected to the aircraft anti-G system (Green 2006b). These AGT are often referred to as partial coverage or 5-bladder anti-G trousers.

AGTs increase +Gz tolerance by providing mechanical tissue compression which increases peripheral vascular resistance and reduces venous pooling in the lower limbs. The abdominal bladder supports the abdominal wall and reduces the displacement of the diaphragm, thereby reducing the heart-to-head distance under +Gz. AGT improve +Gz tolerance by between 1 and 1.5 Gz (Green 2006b).

3.3.2 *The Anti-G Straining Manoeuvre (AGSM)*

The anti-G straining manoeuvre (AGSM) is a learned technique consisting of a co-ordinated, sustained lower body and abdominal muscle contraction combined with a cyclic forced exhalation maintained for 3-4 s against a partially or completely closed glottis, interspaced with rapid inhalations (Green 2006b). It can provide more than a 4 +Gz improvement in G-tolerance if performed correctly (Chen et al. 2004) and the two elements of the manoeuvre will now be discussed in greater detail.

The AGSM requires muscle contraction in order to increase arterial BP through compression of the heart and intrathoracic arteries, increased flow resistance in vascular beds of the lower body and decreased pooling of blood in dependent veins (Kolegard et al. 2013). The magnitude of the muscle contraction is dependent on the size of the muscle mass contracted (MacDougall et al. 1985) and the relative intensity of that contraction (MacDougall et al. 1992). The rise in BP is immediate and considerable, with subsequent smaller and more gradual increases (MacDougall et al. 1985). During heavy resistance exercise involving the lower limb, mean systolic BP can transiently reach a peak of ~ 300 mmHg (MacDougall et al. 1992). This is the result of mechanical compression by the contracting muscles, the accompanying pressor reflex which occurs with static contractions and an elevated intrathoracic pressure caused by the Valsalva manoeuvre (MacDougall et al. 1993).

The Valsalva manoeuvre (VM), or forced exhalation against a closed airway, is associated with a pronounced rise in systolic BP (SBP) directly related to the magnitude of the increase in intrathoracic pressure (MacDougall et al. 1992). It can be divided into four physiological phases; i) onset of strain with a rise of arterial pressure and a decrease in HR, ii) continued strain with drop of arterial pressure followed by partial recovery due to reflex tachycardia and the progressing vasoconstriction, iii) strain release with a sudden drop of arterial pressure, iv) system recovery with arterial pressure overshoot and resulting bradycardia, until BP and HR normalise (Pstras et al. 2016).

The initial phase of the VM will improve +Gz tolerance through an increase in head-level BP, however, if maintained for > 3 s, SBP and HR will reduce as a result of reduced diastolic filing caused by impaired venous return (MacDougall et al. 1992) which will actually lower +Gz tolerance. Under +Gz exposures the VM is interspaced with rapid inspirations of less than 1 s to minimise the strain release period which is characterised by a sudden drop in arterial pressure.

HR and BP responses are more stable for the VM during resistance exercise, and when the VM is combined with heavy resistance exercise has been found to increase BP compared to free breathing (Hackett & Chow 2013). The VM becomes necessary and involuntary during weight lifting ~ 85% maximal voluntary contraction (MVC) or lifts to volitional fatigue (MacDougall et al. 1992). The rise in intra-abdominal pressure (IAP) from the VM increases stability of the spine and is greatest for leg exercises such as squats, dead lifts and leg press (Hackett & Chow 2013). Under +Gz, VM is combined with lower body muscle contraction and has been found to increase +Gz tolerance by +0.9 Gz (Shubrooks & Leverett 1973).

The exercise pressor reflex can also result in elevation of BP due to neural input from skeletal muscles (Secher & Amann 2012). Receptors on both thinly myelinated (group III) and unmyelinated nerve fibres (group IV) located within skeletal muscle are activated by mechanical and chemical stimuli associated with muscle activity (Kaufman 2012). This results in activation of brainstem cardiovascular control areas (Smith et al. 2006), which in turn raises ventilation and circulation (Bruce & White 2012, Secher & Amann 2012).

3.3.3 Performance of the AGSM

The AGSM is extremely effective in improving acceleration tolerance, but the near-maximal muscular contractions can become rapidly tiring which can lead to G-LOC.

Muscle strength, muscle fatigue and aerobic fitness have been surmised to play some role in +Gz tolerance (Bateman et al. 2006). As the AGSM involves muscle contraction, an increase in muscle strength through training may result in a reduced relative effort required to increase head-level BP under a given +Gz stress. A review of patterns of physical conditioning in Royal Australian Air Force (RAAF) fighter pilots suggested that physical fitness is important for operating in the high +Gz environment (Newman et al. 1999).

In an experimental setting +Gz tolerance is often examined using a model of +Gz stress induced in a man-carrying centrifuge. In order to represent the high and low intensity +Gz exposure with similar duration and intensity to that experienced by fast-jet aircrew, the centrifuge profile used to examine +Gz duration is a simulated air combat manoeuvre (SACM) run. This involves alternating +Gz plateaus of +5 Gz for 15 s and +7 Gz for 5 s (Scott et al. 2013) to a visual or fatigue endpoint or measurement of physiological strain (finger BP, blood lactate).

Physical conditioning generally refers to the use of an exercise programme to improve certain components of physical fitness (Bateman et al. 2006). A major portion of the elevation in BP during the AGSM is attributed to contraction of the lower body muscles and is thought to be less fatiguing than the VM element (MacDougall et al. 1993). The effects of muscular strength training on +Gz tolerance has been evaluated during a SACM centrifuge profile by a number of studies, with greater strength shown to substantially increase +Gz duration in some studies (Balldin et al. 1994, Bulbulian et al. 1994, Cao et al. 2012, Tesch et al. 1983), but not all (Bulbulian et al. 1994).

A positive relationship between anaerobic power and tolerance to SACM has been suggested with lower body power (determined by the Wingate anaerobic test (Driss & Vandewalle 2013) on a cycle ergometer) being more highly correlated with SACM duration than upper body anaerobic power (Wiegman et al. 1995). Unfortunately flaws in the experimental design or statistical analysis during these studies confounded interpretation of the results with available research unable to clearly demonstrate whether strength training improved +Gz tolerance (Bateman et al. 2006). A recent study also reported that physical fitness does not seem to be a determinant of +Gz level at which G-LOC during centrifuge training occurs (Park et al. 2016). However, this measured only the association of physical fitness with a G-LOC event during rapid onset (6 $G.s^{-1}$) exposures up to +9 Gz for 15 s.

Fatigue can be defined as a disabling symptom in which physical and cognitive function is limited by interactions between performance fatigability and perceived fatigability (Enoka & Duchateau 2016). Fatigue is a fundamental functional characteristic of skeletal muscle, with muscle fatigue defined as the decrease in force or power production in response to contractile activity (Kent-Braun et al. 2012). Muscle fatigue can be reported as the magnitude of a fall in force or power in response to a contraction protocol, or the duration a contraction can be maintained at a specified submaximal target force (Kent-Braun et al. 2012).

A reduction in peak force, velocity and therefore power is dependent on the intensity of the activation and the fibre-type composition of the muscle (Fitts 1994). Human muscles are composed of three types of muscle fibre. Slow type I (slow oxidative) fibres generate ATP primarily from oxidative metabolism and rely less on glycolysis, making them relatively fatigue resistant (Fitts 1994, Kent-Braun et al. 2012). Fast-contracting type II fibres can be divided into type IIa and IIx. With type IIa fibres being more oxidative and slower contracting relative to the glycolytic, fast-fatigable type IIx fibres. Thus, those muscles dominated by fast fibres (type IIa or fast oxidative glycolytic, and type IIx or fast glycolytic) have a lower oxidative capacity, generate considerable energy from glycolysis and high-energy phosphate stores and are more fatigable than type I fibres. A motor unit is defined as a motor neurone and all the fibres it innervates. Within a motor unit the fibres are of the same type and motor units are recruited in a distinct order (I - IIa - IIx) on the basis of their size (Kent-Braun et al. 2012). Thus, fast fibres are generally recruited during moderate to high workloads (Kent-Braun et al. 2012). There has been no correlation found between muscle fibre type composition in the leg muscles and +Gz tolerance (Tesch & Balldin 1984). If fatigue of the large muscles recruited in the AGSM was a limiting factor in SACM tolerance time, improvements in strength or muscle endurance (or both) may enhance +Gz tolerance.

The mechanisms of muscle fatigue are complex with both the mechanisms involved and their quantitative importance varying depending on the physical activity (Allen et al. 2008). The development of fatigue and impairment of force generation is affected by changes in the nervous, ion, vascular and energy systems. Metabolic factors and fatigue reactants also affect muscle fatigue (Wan et al. 2017) During high workloads, energy stores within muscle are consumed and the products of these reactions accumulate (Allen & Westerblad 2001). At a cellular level, fatigue is caused by the cumulative effect of various metabolite changes which includes impaired calcium (Ca^{2+}) release from the sarcoplasmic reticulum and a subsequent decline in muscle performance (Allen & Westerblad 2001).

During continuing anaerobic exercise, ATP cannot be solely derived from oxidative pathways. Under more intense conditions anaerobic metabolism results in the formation of lactate. Lactate is converted from pyruvate resulting from glycolysis instead of being incorporated into oxidative metabolism and its accumulation in the blood is called the lactate threshold (Sales et al. 2017). This blood lactate threshold is thought to reflect muscular stress and fatigue (Coyle 1995).

Muscle fatigue during prolonged exercise at between 65 – 90% of maximal VO_2 uptake is highly correlated with muscle glycogen depletion (Kent-Braun et al. 2012). Muscle glycogen has been proposed as the primary fuel used by skeletal muscle during the AGSM with a reduction in stores limiting +Gz tolerance, while an accumulation in lactate in the muscle could be a factor in the development of muscle fatigue. Muscle glycogen and lactate measured from the vastus lateralis muscle, and blood lactate measured following SACM profiles, indicated depletion in muscle glycogen and accumulation in lactate (muscle or blood) but the absolute changes were not sufficient to be a limiting factor to fatigue during SACMs and were not related to +Gz tolerance time (Bain et al. 1992). Blood lactate also appears to correlate with maximal HR during +Gz exposures (Burton et al. 1987) with a high correlation between an increase in HR and developing fatigue in a SACM (Burton 1980).

Electromyographic (EMG) activity has been used as an index of muscular fatigue and has been measured during the AGSM in SACM centrifuge profiles in a number of studies (Cornwall & Krock 1992, Bain et al. 1994, Bain et al. 1995). The EMG signal results from the product of motor unit recruitment and firing rate detected from surface electrodes placed over the muscle and is processed and used to measure the degree of muscle activity during a given exercise. The root mean square (RMS) value is often used to monitor changes in activation (De Luca 1997) and increases during prolonged submaximal, constant force contractions (Bain et al. 1994). Frequency analysis of the shape and distribution of characteristic frequencies emitted from the electrical firing pattern of the muscle motor units can also be used with EMG, commonly known as a power spectrum (Bain et al. 1994). During a fatiguing contraction a decrease in the mean power frequency is observed (Bain et al. 1994).

During an AGSM, measurement of bicep femoris, vastus lateralis and gastrocnemius showed no significant change in mean power frequency (Cornwall & Krock 1992, Bain et al. 1994) suggesting that fatigue in these muscles does not limit +Gz tolerance. The average force of the leg extensor muscles generated during a +7 Gz phase of a SACM has been measured as about 35% of MVC force and is unchanged significantly following voluntary exhaustion (Bain et al. 1995).

Respiratory muscle fatigue has been suggested as a limiting factor to +Gz tolerance with increased inspiratory work and decreased pressure generation coinciding with termination of SACM (Bain et al. 1997) and increasing +Gz loads (Whitley 1997). During the VM, high IAP through isometric contraction of the abdominal muscles is associated with higher rectus abdominis muscle activity during sustained high +Gz (Kobayashi et al. 2002). However, an 11 week abdominal muscle training programme did not improve IAP or +Gz tolerance but ratings of perceived exertion during SACMs did improve (Balldin et al. 1985).

An ability to repeatedly execute an efficient AGSM is a major determinant of an individual's +Gz tolerance (Webb et al. 1991), but limited and generally low-quality evidence also suggest improved physical fitness may be a means of increasing this ability.

3.4 Conditioning Programmes

The AGSM represents a highly complex, unnatural, athletic psychomotor skill that takes considerable practice (Bateman et al. 2006). Improved physical fitness has been suggested to enable aircrew of high-performance aircraft to manage the physical demands already discussed. For a conditioning programme to be considered suitable to enhance both +Gz –level and –duration tolerance it must be activity-specific, incorporating both the near-maximal muscular contractions of the large muscle groups and the VM. The role of muscle endurance and the role of respiratory muscle training, with reproduction of the chest strain and particularly the inspiratory component of the AGSM have been suggested to address the perceived fatigue reported by aircrew (Bain et al. 1997).

A means of quantifying +Gz exposure both experimentally and practically needs to be considered. Experimentally, a centrifuge is used to provide a controlled environment with aircrew undertaking specific exposures to assess their relaxed +Gz tolerance (RGT) and their ability to repeatedly perform the AGSM during a SACM profile (+Gz duration tolerance). In-flight confirmation of any centrifuge-based results should also be considered.

To the author's knowledge there has been only one conditioning programme developed to improve +Gz –level or –duration tolerance in aircrew, with the majority of previous literature including studies which focused on improving either strength, anaerobic capacity or reduce neck pain, although there are substantial programmes available to enhance physiologic performance in elite athletes and astronauts.

The United States Air Force (USAF) developed the G-Risk Indicator Management (GRIM) Program to enhance combat capability and safety by identifying aircrew with poor +Gz performance at the Introduction to Flying Fundamentals (IFF) course on the high +Gz capable F-16 aircraft (Galvagno et al. 2004). The GRIM program was designed to assess +Gz tolerance and endurance using scores from the Fighter Aircrew Conditioning Test (FACT) which contained 8 exercise events divided into strength and endurance categories. Whilst the GRIM program did not specifically include a conditioning programme to enhance +Gz tolerance, the exercises contained in the FACT were used by the aircrew to improve +Gz tolerance (Galvagno et al. 2004).

The strength category included 5 exercises (arm curl, bench press, lat pull-down, leg press and leg curl) and the endurance category included three events (push up, abdominal crunch, leg press). A percentage of body mass for each event was used to calculate strength. For endurance, individuals were required to complete 20 repetitions of each event in a 60 s period, with a 60 s rest period between each event. A maximum score was recorded and those that fell below a threshold value received mandated physical conditioning review and frequent assessment of the AGSM (Galvagno et al. 2004).

The GRIM program provided a mechanism for following students with poor +Gz performance, but a review failed to validate the overall preventative capability to lower the risk of G-LOC (Galvagno et al. 2004). Use of the exercises and body mass related minimum loads involved in the FACT could provide a basis for a conditioning programme to enhance +Gz tolerance but adequate assessment in a controlled environment is required.

Parallels have been drawn between elite athletes and astronauts, with some specific effects on the neuromuscular system being similar in both groups (Hides et al. 2017). Prolonged exposure to microgravity (μG) results in reductions of muscle volume and strength, motor control, coordination and balance, bone mass and aerobic capacity, and is associated with lower physical performance capacity (Petersen et al. 2017, Lambrecht et al. 2017). To counteract these effects astronauts, undergo a rigorous inflight exercise countermeasure programme on the International Space Station (ISS) and a post flight reconditioning programme on return (Petersen et al. 2017).

The European Space Agency (ESA) Postflight Reconditioning Programme aims to restore postural control, motor control and muscle balance using motor learning principles, with strength training added after correct postural alignment is regained (Lambrecht et al. 2017). Targeted neuromuscular exercise-based injury preventative training programmes have also been developed for specific occupational cohorts (Padua et al. 2014). A preflight training programme has also been developed by ESA and has been likened to pre-season training in elite sport, with the aim to have the astronaut in the best possible physical condition prior to joining the ISS.

3.4.1 Neck Pain

Neck pain within military pilots is recognised as a challenging problem in modern air forces, with an estimated one-year prevalence approaching 50% (Ang & Harms-Ringdahl 2006). Discomfort in the cervical region of fighter pilots is associated with deviated head postures (Ang et al. 2005), unpreparedness for high +Gz manoeuvres (Lange et al. 2011), and/or repeated exposure to forces ≥ +4 Gz (Burnett et al. 2004).

While flying at +9 Gz, the fighter pilots head and headgear can exert loads of 50 – 70 kg on the neck (Lange et al. 2011, Harms-Ringdahl et al. 1999). The internal forces may be even higher as a result of the biomechanical alterations that occur when the head deviates from the neutral position, such as in the 'check-six position' which is a combination of full cervical spine rotation, lateral flexion and extension (Harms-Ringdahl et al. 1999).

Fighter pilots with frequent episodes of neck pain have comparatively low neck extensor muscle strength, perhaps experiencing pain due to their inability to protect and stabilise the head and neck in high +Gz environments. Higher muscle strength might significantly affect aircrew performance when pulling high +Gz forces (Ang et al. 2005) and in turn enhance +Gz tolerance (Bateman et al. 2006). Provision of neck specific exercises in a conventional resistance training programme is necessary to increase the cross-sectional area of the neck musculature and thus neck extension strength. Isometric contractions of the cervical spine muscles at the level of contraction required for stabilisation during a conventional resistance training programme are of insufficient intensity to generate hypertrophy (Conley et al. 1997).

3.5 G-Induced Loss of Consciousness (G-LOC)

An inability to perform an effective AGSM can result in G-LOC or almost loss of consciousness (A-LOC). G-LOC may result in a period of incapacitation (lack of purposeful movement) lasting 30 seconds or more, consisting of a period of absolute incapacitation (unconsciousness) and relative incapacitation (confusion/disorientation) (Whinnery & Whinnery 1990). A-LOC refers to the signs and symptoms that do not include the complete loss of consciousness and is associated with the disconnection between the desire and the ability to perform an action (Morrissette & McGowan 2000). It is characterised by a number of physiological, emotional and cognitive signs and symptoms, and features include sensory abnormalities, amnesia, confusion, euphoria, loss of short-term memory, paralysis, reduced auditory acuity, and motor abnormalities (Shender et al. 2003). These are similar to the relative incapacitation phase of G-LOC and have led to the concept of a G-LOC Syndrome with a broad spectrum of possible neurologic manifestations (Shender et al. 2003) which can result in serious motor and cognitive impairments in the high +Gz environment.

The signs and symptoms of G-LOC were reported as early as 1918 (Head 1920) but active determination of G-LOC incidence did not begin until 1982 (Lyons et al. 1992). A number of military air forces have surveyed the incidence of G-LOC and A-LOC in their aircrew over the last twenty years. These studies have indicated that ~ 8 – 20% of military aircrew have experienced G-LOC (Alvim 1995, Cao et al. 2012, Rickards & Newman 2005) and 14 – 52% have experienced A-LOC (Morrissette & McGowan 2000, Rickards & Newman 2005) at some point in their career. The RAF conducted two surveys of G-LOC within their military aircrew in 1987 (Prior 1987) and 2005 (Green & Ford 2006), with 19.3% and 20.1% respectively of aircrew reporting such an event at some point in their career.

3.6 Summary

Operating in a high +Gz environment can be physically challenging due to the effect of +Gz acceleration on the cardiovascular system. As +Gz acceleration increases, effective circulating volume and head-level BP reduces due to an increased hydrostatic pressure gradient in the vascular system, and venous pooling in the lower limbs. The baroreceptor reflex compensates for this with an increase in HR and peripheral vasoconstriction however this is insufficient to maintain adequate head-level BP and cerebral oxygenation > +5 Gz or with rapid onset +Gz acceleration.

To counter these effects the AGSM is used. It is extremely effective in improving +Gz acceleration tolerance but can become rapidly tiring and may lead to G-LOC.

3.7 Thesis Outline

No prior work has systematically examined the effect of a whole-body exercise programme on the ability to tolerate +Gz acceleration. The first chapter (Chapter 4) investigates the present status of +Gz related incidents in the RAF via an anonymised questionnaire distributed to all serving RAF pilots and weapons systems operators irrespective of aircraft currently flown. The principle objective of the survey is to determine the prevalence of G-LOC and almost loss of consciousness (A-LOC) in the RAF which will enable identification of aircrew groups potentially most at risk. The survey will also determine the level of +Gz awareness within RAF aircrew and attitudes towards various measures designed to reduce the incidence of G-LOC and A-LOC. In Chapter 5, an exercise programme (Aircrew Conditioning Programme - ACP) designed to enhance aircrew performance through improvements in the ability to repeatedly perform an effective AGSM and reduce strain injuries to the neck, enhancing the ability to lookout of the cockpit, will undergo content validation by a panel of experts for appropriateness for delivery to an aircrew population by a team of trained physical training instructors and physiotherapists. Chapter 6 is the main experimental chapter which will investigate the efficacy of the ACP performed for 12 weeks on i) relaxed and staining +Gz-level tolerance, ii) +Gz-duration tolerance to repeated high sustained +Gz during a series of simulated air combat manoeuvre profile centrifuge runs, and iii) associated physiological parameters. This study will determine whether the ACP would have a beneficial effect on aircrew performance in a controlled high +Gz environment.

Chapter 4 Incidence of G-Induced Loss of Consciousness and Almost-Loss of Consciousness in the Royal Air Force

4.1 Introduction

Exposure to high levels of +Gz acceleration may result in G-LOC or A-LOC as discussed previously. +Gz protection is usually enhanced for fighter pilots by the use of AGSM and anti-G trousers. If the AGSM is not performed, or is inadequate, then G-LOC is more likely (Lin et al. 2012). Following this some aircrew may require further time (up to two minutes or longer) to fully recover and regain cognition with the capacity to act effectively (Lin et al. 2012). This can cause a significant occupational hazard to aircrew of high-performance aircraft and has resulted in catastrophic consequences with aircraft and personnel loss. The RAF conducted two surveys of G-LOC within their military aircrew in 1987 (Prior 1987) and 2005 (Green & Ford 2006), with 19.3% and 20.1% respectively of aircrew reporting such an event at some point in their career.

Following the 2005 survey, centrifuge-based +Gz training was introduced for all UK Ministry of Defence (MOD) fast-jet aircrew at an early stage in their flying career, and additionally included aircrew converting to high performance aircraft such as the Typhoon (capable of up to +9 Gz with an onset rate of ≥ 8 $G.s^{-1}$). Since then there has been no measure of the prevalence or awareness of A-LOC within RAF aircrew, although the first documented fatality attributed to A-LOC was reported in 2012 (Military Aviation Authority 2012).

The aim of this study was to re-assess the prevalence of G-LOC in the RAF and additionally to determine the prevalence of A-LOC in view of the widespread introduction of centrifuge training since the previous survey. This survey should enable identification of aircrew groups potentially most at risk. In addition, the survey was intended to determine the level of +Gz awareness within the RAF aircrew and attitudes towards various measures designed to reduce the incidence of G-LOC and A-LOC. This survey included 5 years of operational service of the +9 Gz capable Typhoon aircraft, which was not fully operational in previous surveys.

4.2 Methods

4.2.1 Data Collection

An anonymised questionnaire (Appendix 1) requesting details of G-LOC and A-LOC events was designed by the author and based on the RAF Centre of Aviation Medicine (RAF CAM) questionnaire used in the previous RAF G-LOC surveys. The questionnaire was distributed in 2012 to all currently serving RAF pilots (n = 1878) and weapons systems operators (WSOs) (n = 473) (total n = 2351 aircrew), irrespective of aircraft currently flown (including rotary wing and multi-engine aircraft). The aim was to gain information not only from current fast jet aircrew, but also those who may have previously experienced G-LOC or A-LOC in training aircraft. In the UK, rotary wing aircrew are able to transfer to instructor roles on training aircraft during their flying career.

The same questionnaire from the previous RAF surveys (Green & Ford 2006, Prior 1987) was used in order to allow comparison of results, with the addition of questions asking the aircrew to describe any A-LOC event suffered and frequency, and details of any regular physical conditioning training (aerobic, anaerobic and strength training) they had participated in, and whether they had participated in centrifuge training.

Anonymous responses were returned by mail, in a stamped addressed envelope in order to encourage full and honest reporting. Data collected included basic details (age, current aircraft and role), in addition to whole career G-LOC and A-LOC experience and, if either was reported, details of the most significant incident. A definition of ‘most significant’ was not provided in the survey, but rather it was assumed that aircrew would describe the incident remembered most vividly or of most significant threat to safety. In cases where respondents reported more than one episode, only one event was included in the subsequent analysis, using details of the most significant G-LOC or A-LOC episode reported. Details included approximate date of the incident, aircraft type, level of experience at the time of the incident (hours on type and total hours), whether the respondent was controlling the aircraft at the time of the incident, maximum +Gz, +Gz onset rate (information for both is available to the pilot when flying and should be monitored as part of routine flight), whether the aircraft was unloaded prior to the manoeuvre which caused the incident (exposure to -Gz reduces tolerance to a following +Gz exposure), whether the respondent was performing an AGSM, and was the respondent wearing a functioning anti-G suit.

Attitudes towards various measures designed to reduce the incidence of G-LOC/A-LOC were assessed; flying currency (number of hours flying experience on the current aircraft type), centrifuge training, conditioning training, use of an anti-G suit, and G theory lectures. Respondents were asked to rate the measures in terms of importance using a 4-point ordinal Likert rating scale (1 – not at all, 2 – not very, 3 – fairly, 4 – very). They were also asked how often they participated in regular aerobic or anaerobic conditioning and strength training, using the same Likert scale. A positive response to the questions was calculated as the number of respondents rating the measures and exercises ‘very’ or ‘fairly’. A 4-point scale was used to avoid having a neutral and ambivalent midpoint.

Data from returned questionnaires were captured electronically using an optical marker system (Remark Office OMR 8.0, Gravic, Malvern, PA). The study protocol was approved in advance by the RAF Experimental Medicine Scientific Advisory Committee and the Ministry of Defence Research Ethics Committee (Ref: 362/GEN/12).

4.2.2 Statistical Analysis

The full cohort was described using descriptive statistics for categorical data. Aircrew who had experienced an A-LOC or G-LOC and had reported their most significant event, were also described and compared against level of experience using the chi-square test. Attitudes to anti-G-LOC measures were compared by age and level of experience using the chi-square test with α set at $p < .05$. Statistical analysis was performed using SPSS software (v 22.0.1, SPSS Inc, Chicago, IL) and Stata SE v12.0 (StatCorp, College Station, TX, USA).

4.3 Results

The questionnaire was returned by 809 of the 2351 aircrew (34.4% response rate), of whom 615 were pilots and 194 were WSOs. The median age-category of responders was 30 – 34 years. The largest group to respond were fast jet aircrew (n = 258, 31.9%), with multi-engine (n = 154, 19.0%), rotary (n = 135, 16.7%), ground tour (n = 109, 13.5%), Intelligence, Surveillance, Target Acquisition & Reconnaissance aircraft (ISTAR) (n = 57, 7.1%), light aircraft trainer (n = 52, 6.4%), and test flying/other (n = 44, 5.4%) also represented.

At least one episode of A-LOC or G-LOC was reported by 301 (37.2%) of responding aircrew. A total of 120 (14.8%) reported at least one episode of G-LOC and 260 (32.2%) reported at least one episode of A-LOC. Whilst 79 (9.8%) aircrew reported at least one episode of both G-LOC and A-LOC.

A total of 292 (36.1%) aircrew described their most significant A-LOC (n = 188, 23.2%) or G-LOC (n = 104, 12.9%) event. Of the 517 (63.9%) non-responses for this section of the questionnaire, 508 (62.8%) reported having never experienced an A-LOC or G-LOC event and 9 (1.1%) had experienced an A-LOC or G-LOC event but did not describe it. Aircrew who reported an event and those who did not had similar age groups ($p < .097$), current roles ($p = .124$) and current aircraft ($p < .039$) except for fast jet. Of the fast jet aircrew, 106 (36.0%) reported an event *vs* 152 (29.0%) who had not reported an event, ($p < .043$).

In those aircrew who reported an event, G-LOC and A-LOC were reported to have occurred most commonly during training (n = 63 (60.6%) suffered G-LOC and n = 111 (59.0%) suffered A-LOC), but were also reported by aircrew at instructor level (n = 19 (18.3%) G-LOC and n = 39 (20.7%) A-LOC), squadron (line) pilot level (n = 11 (10.7%) G-LOC and n = 25 (13.4%) A-LOC), and test pilots and other miscellaneous groups (n = 10 (9.6%) G-LOC and n = 11 (5.9%) A-LOC) (Figure 4.1).

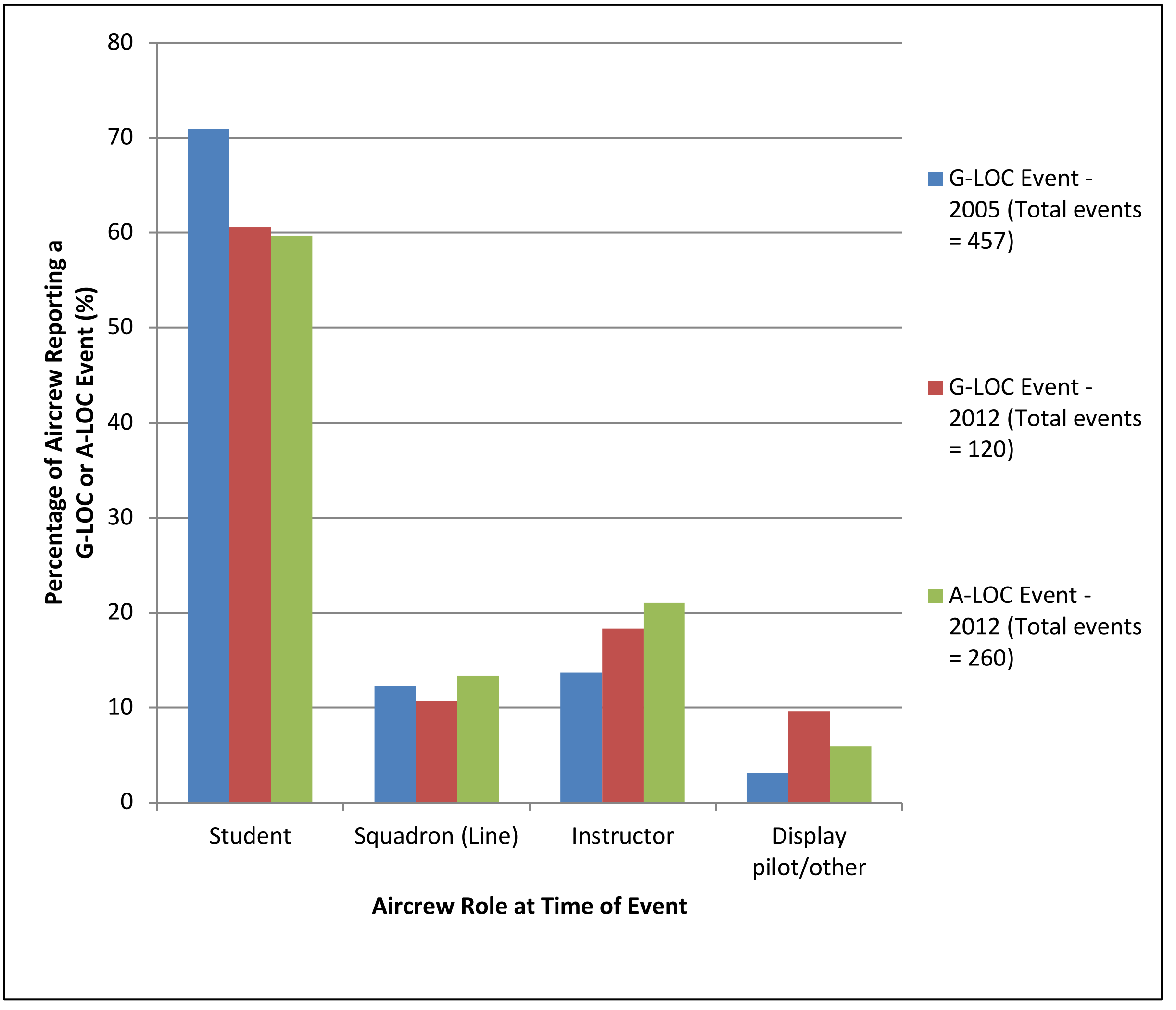

Figure 4.1 Percentage of aircrew reporting G-induced Loss of Consciousness (G-LOC) / Almost-Loss of Consciousness (A-LOC) events broken down by role from the 2005 survey (457 reported a G-LOC event) and the 2012 survey (301 reported either a G-LOC or A-LOC event, and 79 aircrew reported both G-LOC and A-LOC events).

The types of aircraft in which G-LOC and A-LOC were experienced were predominantly trainers including the Hawk, Tucano and Grob Tutor, making up 68 (65.4%) of the G-LOC and 134 (71.3%) of the A-LOC totals (Table 4.1). G-LOC events in front line (operational) aircraft accounted for 4 (3.9%) of total episodes, and A-LOC for 25 (13.4%). If only current fast jet aircrew are considered and aircrew in all other roles are excluded, 38 (36.5%) reported a G-LOC event and 68 (36.2%) reported an A-LOC event.

Aircraft type	Number reporting G-LOC		Number reporting A-LOC
	2005 (n=433)	2012 (n=103)	2012 (n=186)
Hawk (trainer aircraft)	106 (23.3%)	35 (34%)	66 (35.5%)
Tucano (trainer aircraft)	71 (15.6%)	28 (27.2%)	49 (26.3%)
Jet Provost (trainer aircraft) †	175 (38.5%)	21 (20.4%)	12 (6.5%)
Grob Tutor (trainer aircraft)	0 (0%)	5 (4.9%)	19 (10.2%)
Bulldog (trainer aircraft) †	21 (4.6%)	5 (4.9%)	4 (2.2%)
Tornado GR1/GR4 (frontline aircraft)	4 (0.9%)	3 (2.9%)	9 (4.8%)
Tornado F3 (frontline aircraft) †	7 (1.5%)	1 (1%)	10 (5.4%)
Typhoon (frontline aircraft)	*	0	5 (2.7%)
Firefly (trainer aircraft) †	8 (1.8%)	0	4 (2.2%)
Harrier (frontline aircraft) †	1 (0.2%)	0	1 (0.5%)
Hunter (frontline aircraft) †	3 (0.7%)	0	1 (0.5%)
Other	37 (9.3%)	5 (4.9%)	6

Table 4.1 Aircraft type at G-induced Loss of Consciousness (G-LOC) / Almost Loss of Consciousness (A-LOC) event in the 2012 survey compared against the 2005 survey. * Typhoon came into RAF Service following the 2005 survey. † No longer in RAF Service at the time of the 2012 survey.

G-LOC was most common in aircrew with < 100 hours experience on that type of aircraft (n = 65, 63.1%), with A-LOC prevalence at 110 (58.8%). Both were also more prevalent in aircrew with < 249 total flying hours in their careers (G-LOC = 61 (58.7%), A-LOC = 95 (50.5%)).

Since the last survey of RAF aircrew and the introduction of centrifuge training in 2005, for all fast-jet aircrew early in their training, a total of 47 G-LOC and 127 A-LOC events have been reported (Figure 4.2).

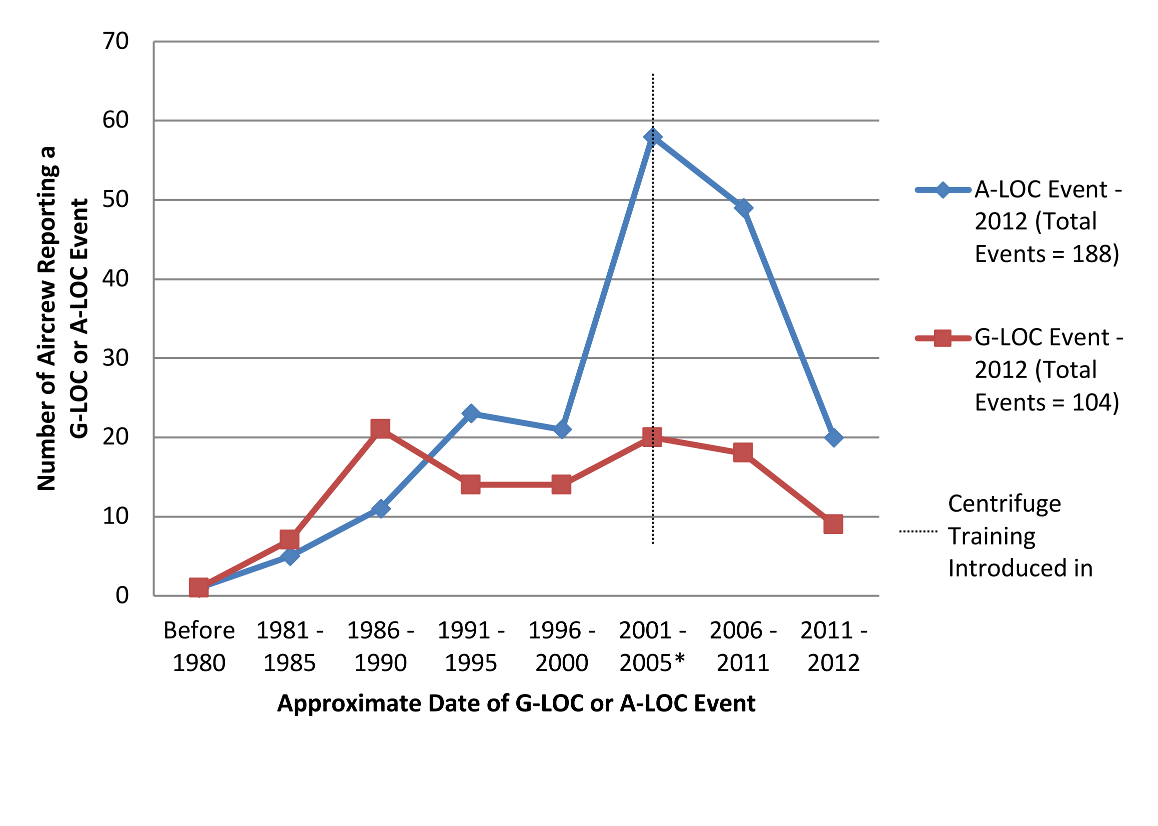

Figure 4.2 Number of aircrew reporting a G-induced Loss of Consciousness (G-LOC) / Almost Loss of Consciousness (A-LOC) event broken down by the approximate date from the 2012 survey (total of 104 aircrew reported a G-LOC event and 188 reported an A-LOC event). *Centrifuge training was introduced for all fast-jet aircrew early in their training in 2005.

G-LOC or A-LOC occurred in the range of +4 to +9 Gz, with the majority of cases occurring at +5 to +5.9 Gz (n = 32 (32.7%) for those reporting a G-LOC event and 60 (35.3%) for A-LOC). Acceleration onset rate was described as 'rapid' in 94 (92.2%) of G-LOC and 153 (83.2%) of A-LOC events. The majority of G-LOC (n = 83, 80.6%) and A-LOC (n = 127, 67.6%) events were experienced by aircrew who were not controlling the aircraft at the time. G-LOC and A-LOC after exposure to acceleration at < 1 Gz prior to positive Gz (commonly referred to as 'push pull') featured in 24 (24.5%) of G-LOC and 46 (25.6%) of A-LOC events. Only 58 (56.3%) of aircrew claimed to be performing an AGSM when G-LOC occurred, but 134 (71.7%) were straining when A-LOC occurred. The majority of aircrew were not wearing a functioning anti-G suit when G-LOC occurred (n = 75, 72.1%) as there is no anti-G system in the Grob Tutor or Tucano trainer aircraft.

Ninety-two (49.5%) aircrew experiencing an A-LOC event were using a functioning anti-G suit.

The survey included a series of questions concerning Gz awareness and the perceived value of training in the prevention of G-LOC and A-LOC. The importance of flying currency was recognised by 94.2% of respondents, 95.1% the use of an anti-G suit, 87.7% attendance of Gz-theory lectures, 84.2% participation in physical conditioning training, and 72.8% considered centrifuge training important (Table 4.2). Notably, only 249 (30.8%) respondents reported that they had participated in centrifuge training.

How important do you consider each of the following in reducing instances of G-LOC & A-LOC?	**2005*** (n=2259)	**2012*** (n=809)
Flying currency	90.1 (2037)	94.2 (772)
Anti-G suit	87.6 (1987)	95 (745)
Physical conditioning	82.7 (1869)	84.2 (748)
Classroom G-theory lectures	80.3 (1815)	87.7 (758)
Centrifuge training	55.6 (1255)	72.8 (720)

Table 4.2 Comparison of the percentage of aircrew responding positively (‘very’ or ‘fairly’ important) to a series of questions concerning +G awareness and perceived value of training in the prevention of G-induced loss of consciousness (G-LOC) and Almost Loss of Consciousness (A-LOC) in the 2005 and 2012 surveys.

Of the 287 aircrew who reported either a G-LOC or A-LOC event, 194 (67.6%) felt that centrifuge training was either ‘very’ or ‘fairly important’ in reducing instances of G-LOC or A-LOC. A total of 524 felt that centrifuge training was of value, with 330 (62.9%) having not experienced a G-LOC or A-LOC event ($p < .048$).

Respondents were also asked how often they participated in regular exercise. The majority participated in regular aerobic conditioning (624) with 376 (60.7%) participating in 2-3 sessions per week. A total of 234 respondents (49.7%) participated in one weekly anaerobic session (self-defined by the respondents), with 200 (42.5%) participating in 2-3 sessions weekly. This was similar for regular strength training (483 total respondents), with 230 (46.9%) participating in one and 215 (43.9%) participating in 2-3 sessions per week. Unfortunately, the 2005 survey did not ask aircrew if they participated in any form of exercise, preventing direct comparison with the 2012 survey. There was also no option for aircrew to indicate if they performed no exercise in the 2012 survey as it was assumed they would complete at least one exercise session per week.

In the 2012 survey (n = 809) compared with that of 2005 (n = 2259), there was a lower prevalence of G-LOC (14.8% and 20.1% respectively, $p < .001$). Compared with the 2005 survey (454) those who described their G-LOC experience in the 2012 survey (104) had less flying experience, with a higher proportion of events being reported in aircrew with < 250 hours total flying hours (78.0% and 64.0% of GLOC occurrences respectively, $p < .001$). There was increased reporting of G-LOC in the Hawk, Tucano and Grob Tutor aircraft.

4.4 Discussion

The reported prevalence of G-LOC events in the RAF reduced from 20.1% in 2005 to 14.8% in 2012. A-LOC was reported by 32.2% of respondents in the 2012 survey. The G-LOC prevalence rate is generally in line with other military defence forces that have surveyed their aircrew in the last 20 years, reporting incidences of 8 – 20% (Alvim 1995, Green & Ford 2006, Shender et al. 2003). However the prevalence of reported A-LOC (32.2%) in RAF aircrew is higher than reported in a survey involving aircrew from the US Navy, Marine Corps and Air Force (14%) (Morrissette & McGowan 2000), but less than aircrew in the Royal Australian Air Force (RAAF) (52%) (Rickards & Newman 2005). The higher prevalence for the RAAF may be as a result of their aircrew being verbally briefed on the signs and symptoms of A-LOC prior to completing the survey. An increase in reporting of A-LOC from 2000 is noted in the literature (Morrissette & McGowan 2000, Rickards & Newman 2005), with the term 'A-LOC Syndrome' coined in 2003 (Shender et al. 2003). This may in part be due to an increased awareness of the phenomenon in both the aeromedical and aircrew community. The 2005 RAF survey (Green & Ford 2006) did not ask aircrew about any possible A-LOC experiences.

G-LOC and A-LOC prevalence may be higher in both RAF surveys than other military defence forces (G-LOC incidence of 8 – 10% (Alvim 1995, Yilmaz et al. 1999) and A-LOC incidence of 14% (Morrissette & McGowan 2000)) due to methodological differences. Lower incidences of both have been reported in studies that surveyed only current fast-jet aircrew (Alvim 1995, Morrissette & McGowan 2000, Yilmaz et al. 1999) which may have resulted in missing some people who experienced a G-LOC or A-LOC event early in their flying training but then went on to non-high performance aircraft. In all three RAF surveys (Green & Ford 2006, Prior 1987), aircrew flying non-high performance aircraft were questioned, yet G-LOC was reported in 44% and A-LOC in 43.6% of non-fast jet (transport, rotary, light aircraft and ISTAR) aircrew. This is likely to relate to experiences during the various stages of their flying training as all RAF aircrew complete elementary flying training in a light aircraft (currently the Grob Tutor) prior to being streamed to fast jet, rotary wing or transport/multi-engine aircraft.

The relatively low response rate of 34% to the current survey may be a result of 'survey fatigue' within the population. The survey was posted to all registered RAF aircrew regardless of current role or geographical location, with follow up emails to all squadron commanders requesting them to encourage aircrew to return the completed survey. Every effort was made to obtain a representative sample of the population however, an element of selection bias may have occurred. A number of aircrew contacted the investigators to enquire if they should complete the survey despite having a predominantly rotary or transport aircraft background and no experience of G-LOC or A-LOC. They were advised to do so as the aim was to include flying training in the broader examination of G-LOC/A-LOC prevalence. It is possible that only aircrew who had experienced an event returned the survey. It is also possible that some may have experienced an incident and did not respond for fear of being removed from flying duties. A verbal brief to aircrew prior to distributing the survey which explained its purpose, and the signs and symptoms of both G-LOC and A-LOC may have encouraged a greater response rate. This would require a significant change in how the questionnaire was distributed and should be considered with future studies. The response rate may also be confounded by the very nature of G-LOC and A-LOC, in that aircrew can suffer from poor recall and amnesia following an incident (Cao et al. 2012) and this might result in under-reporting.

The prevalence of reported events remains high in aircrew under training (G-LOC 60.6%, A-LOC 59.0%) although it has reduced from the previous survey (G-LOC 70.9%). Similarly, the predominant trainer aircraft (Hawk, Tucano, Grob Tutor) accounted for 65.4% of G-LOC and 71.3% of A-LOC events (Table 4.1). This was slightly reduced from the 77.4% of G-LOC events reported in 2005 and may result from the introduction of centrifuge-based training for all fast jet aircrew prior to the Tucano flying phase.

The centrifuge training involves two sessions conducted in one day. The first consists of a series of graduated runs wearing no countermeasures, progressing from +3.5 Gz for 15 s up to +5.5 Gz for 15 s. Following a break of a few hours, the second session consists of a series of graduated runs wearing five-bladder anti-G trousers, progressing from +4.5 Gz for 15 s up to +7 Gz for 15 s. The runs enable compliance with STANAG 3827 although the centrifuge is only capable of an onset rate of 1 $G.s^{-1}$. Since 2005, there has also been a new G-limit of +5 Gz (previous G-limit was +6 Gz) introduced for the Tucano aircraft to reduce fatigue life on the airframe which may also have contributed to the fall in G-LOC events compared with the 2005 survey.

Of concern is the number of aircrew who have reported either a G-LOC (n = 5) or A-LOC (n = 19) event in the Grob Tutor, as none were reported in 2005. All RAF aircrew commence their flying training on the Grob Tutor aircraft and as such have minimal flying experience. As part of their training, they receive classroom-based Gz theory lectures and basic AGSM instruction. In light of the results of this survey, it may be prudent to develop the current Gz theory lectures for all aircrew on the Grob Tutor to include a more formal practice of a correct AGSM technique which could involve centrifuge training. Centrifuge training is deemed by many to be extremely important, by providing the opportunity to practice an effective and efficient AGSM technique in a non-threatening environment (Sevilla & Gardner 2005, Yilmaz et al. 1999), which may play a role in protecting aircrew against high +Gz forces in the operational environment (Sevilla & Gardner 2005).

Student aircrew reported a higher incidence of both +Gz events, presumably due to their relative inexperience in both Gz awareness and ability to perform an effective AGSM (Sevilla & Gardner 2005). This may account for the relatively unchanged number of aircrew who claimed to be performing an AGSM when G-LOC (56.3% in 2012 and 55.3% in 2005) and A-LOC (71.7%) occurred. It seems reasonable to conclude that their AGSM was inadequate, started too late during the manoeuvre and unable to produce sufficient muscle-tension to counteract the increased hydrostatic pressure of blood as it pools in the legs ('behind the G'), or that the individuals were too fatigued to maintain sufficient head-level blood flow during the manoeuvre. G-LOC events may be related to fatigue and/or complacency. A timely and proficient AGSM is essential for all high +Gz exposures (Whinnery & Forster 2013).

The RAF rate for G-LOC events may have reduced as a consequence of the introduction of centrifuge-based training following the last survey which occurred for all fast jet streamed aircrew at an early stage in their flying career, and for those converting to high performance aircraft such as Typhoon. However, it should be noted that only 33% of respondents had participated in centrifuge training, with the others having undergone flying training before this policy was introduced. Of the 105 who reported a G-LOC event, 55.2% had not completed centrifuge training. Due to the structure of the survey, it is unclear whether those who did report a G-LOC event had completed centrifuge training prior to the event. Future surveys should include more detail of centrifuge training and whether aircrew felt this training enhanced their ability to recognise G-LOC or A-LOC symptoms. Some UK operational / frontline aircraft exhibit an onset rate of at least 8 $G.s^{-1}$ (Typhoon), but these aircrew receive aircraft based high +Gz onset top up training.

Respondents were asked a series of questions concerning Gz awareness and their perceived value of training in the prevention of G-LOC and A-LOC (Table 4.2). The number responding positively ('very' or 'fairly' important) increased for all the questions when compared with 2005. This suggests that awareness of basic prevention measures was high, although the issue of selection bias should be considered. The perceived importance of centrifuge training increased the most amongst responders (72.8% in 2012 and 55.6% in 2005). A total of 524 aircrew felt that centrifuge training was of value, with 330 (62.9%) having not experienced a G-LOC or A-LOC event ($p < .048$).

The ability to perform an effective AGSM and reduce the fatigue associated with it has been recommended to prevent G-LOC (Sevilla & Gardner 2005). As the AGSM involves muscle contraction, an increase in muscle strength through training may result in a reduced relative effort required to increase head-level BP under a given +Gz stress. Physical conditioning including both anaerobic and aerobic fitness training (Sevilla & Gardner 2005) and general strength training of muscle groups involved in the AGSM (Bateman et al. 2006) could combat the fatigue reported by aircrew.

Limitations of this study are the relatively low response rate of 34% for the G-LOC survey which could be improved through providing a verbal brief to aircrew prior to distribution of the survey. The brief should explain the purpose, and signs and symptoms of both G-LOC and A-LOC which may encourage a greater response rate. Future surveys should also include more detail of centrifuge training and whether aircrew felt this training enhanced their ability to recognize G-LOC or A-LOC symptoms.

4.5 Conclusion

Whilst the prevalence of reported G-LOC has decreased since the previous survey from 20.1% to 14.8%, G-LOC remains a hazard to all aircrew, particularly during the initial stages of flying training. This is highlighted by the responding RAF aircrew reporting 5 G-LOC and 19 A-LOC events in the Grob Tutor all since the 2005 survey. Measures to significantly reduce the incidence of these events in this group should be taken and could include more formalised +G theory classroom lectures and correct execution of the AGSM and centrifuge training earlier than currently undertaken. G-LOC and A-LOC thus remain significant concerns despite the current countermeasures. Further approaches must therefore be explored. One of these is the focus of the rest of this thesis: the design, content validation and evaluation of an aircrew conditioning programme targeted at improving performance under +Gz.

Chapter 5 Content Validity of the Aircrew Conditioning Programme

5.1 Introduction

The ability to operate in a high +Gz environment is physically demanding particularly if repeatedly executing the AGSM or attempting to lookout of the cockpit. An ineffective AGSM may lead to loss of consciousness as discussed in Chapter 4. Repeated exposure to high +Gz whilst attempting to move the head can result in neck pain and/or injury. Both of these consequences may have a broader effect on operational performance, affecting the capacity of aircrew to manage +Gz stress and remain injury free.

Neck pain within military pilots is recognised as a challenging problem in modern air forces, with an estimated one-year prevalence approaching 50% in helicopter pilots (Ang & Harms-Ringdahl 2006). Most injuries reported among fast-jet aircrew are described as strain of the neck muscles, with occasional neck pain and neck stiffness, related to frequent exposure to high +Gz forces in high performance jet aircraft (Ang et al. 2005). The prevalence of flight-related neck pain in all RAF aircrew is 66% (Wickes & Greeves 2006); with 70% of UK fast-jet aircrew reporting flight-related neck pain (Wickes & Greeves 2006). Physical conditioning programmes may reduce these injuries, which would in turn enhance pilot performance. To date the RAF has no specific structured strategy to deal with this issue.

The physical forces encountered during +Gz exposure may lead to fatigue and injury, particularly if executing the AGSM. Muscle strength and fatigue, and aerobic fitness may therefore have a role in +Gz tolerance (Bateman et al. 2006). An inability to perform an effective AGSM can result in G-LOC or A-LOC.

The United States Air Force (USAF) developed the Fighter Aircrew Conditioning Test (FACT) as part of the G-Risk Indicator Management (GRIM) Program to enhance combat capability and safety by identifying aircrew with a tendency for poor G-performance and assisting them with the development of habits which would enhance G-tolerance. The FACT contains 8 exercise events divided into strength and endurance categories; however, a programme review failed to validate the overall preventative capability for G-LOC (Galvagno et al. 2004). To counter the effects of prolonged exposure to microgravity, astronauts undergo a rigorous inflight exercise countermeasure programme on the International Space Station (ISS) and a post flight reconditioning programme on return (Petersen et al. 2017). A coordinated training programme focusing on neck muscle control, with low load exercises to enhance the coordination of the cervical musculature has been suggested for military aircrew (Salmon et al. 2011).

The Aircrew Conditioning Programme (ACP) has been developed by the author in response to some of the results from the survey undertaken as part of Chapter 4. The ACP is a structured and progressive exercise programme which aims to enhance aircrew performance through improvements in the ability to repeatedly perform an effective AGSM and reduce strain injuries to the neck, enhancing the ability to lookout of the cockpit.

The aim of this study was to assess the content validity of the ACP for appropriateness for delivery to an aircrew population and for delivery by a team of trained physical training instructors (PTIs) and physiotherapists.

5.2 Aircrew Conditioning Programme (ACP)

The ACP has been designed as a preventative strategy for aircrew with no current injury, delivered to qualified aircrew and all student aircrew within the Flying Training (FT) pipeline, regardless of phase of training or aircraft type. It has been designed to become more role and platform specific as student aircrew progress through the FT, with minimum standards recommended for each stage.

The ACP should be delivered by trained PTIs who complete a 5 day instruction course covering all components of the ACP, and a physiotherapist who completes a one day course covering the specialist areas of assessment which includes neck muscle strength and range of motion. The physiotherapist also delivers a presentation at the start of each stage of FT which provides an overview of the ACP and the reasons behind its use.

As part of the ACP, aircrew receive a period of supervised instruction in small groups in all the exercises enabling them to continue their individualised conditioning programme independently. The ACP sessions are delivered during mandated periods during both the ground school and flying phases of training. The hourly sessions are delivered twice a week for 12 weeks, with aircrew required to attend all the supervised sessions.

The ACP consists of 4 main components; i) whole body flexibility and mobility, ii) cardiovascular fitness, iii) stability and motor control of the neck, shoulder girdle and trunk, and iv) strengthening exercises of the neck, back, abdominal and leg muscles. Each exercise session consists of a combination of those components (Figure 5.1). Whole body flexibility and mobility exercises which include general stretching exercises and use of a foam roller to the main muscle groups are advised for all ACP levels. The aim of the stability and motor control exercises is to maintain a neutral cervical spine posture under load in all positions and develop rotational core control in a seated position. The weight is only increased with the strengthening exercises once initial technique is appropriate and safe, and the technique must be maintained throughout the movement as the load is increased. All neck exercises are performed isometrically in a spinal neutral position with low loads of 1 – 4kg. At all times aircrew are encouraged to maintain a neutral cervical spine position through activation of the deep

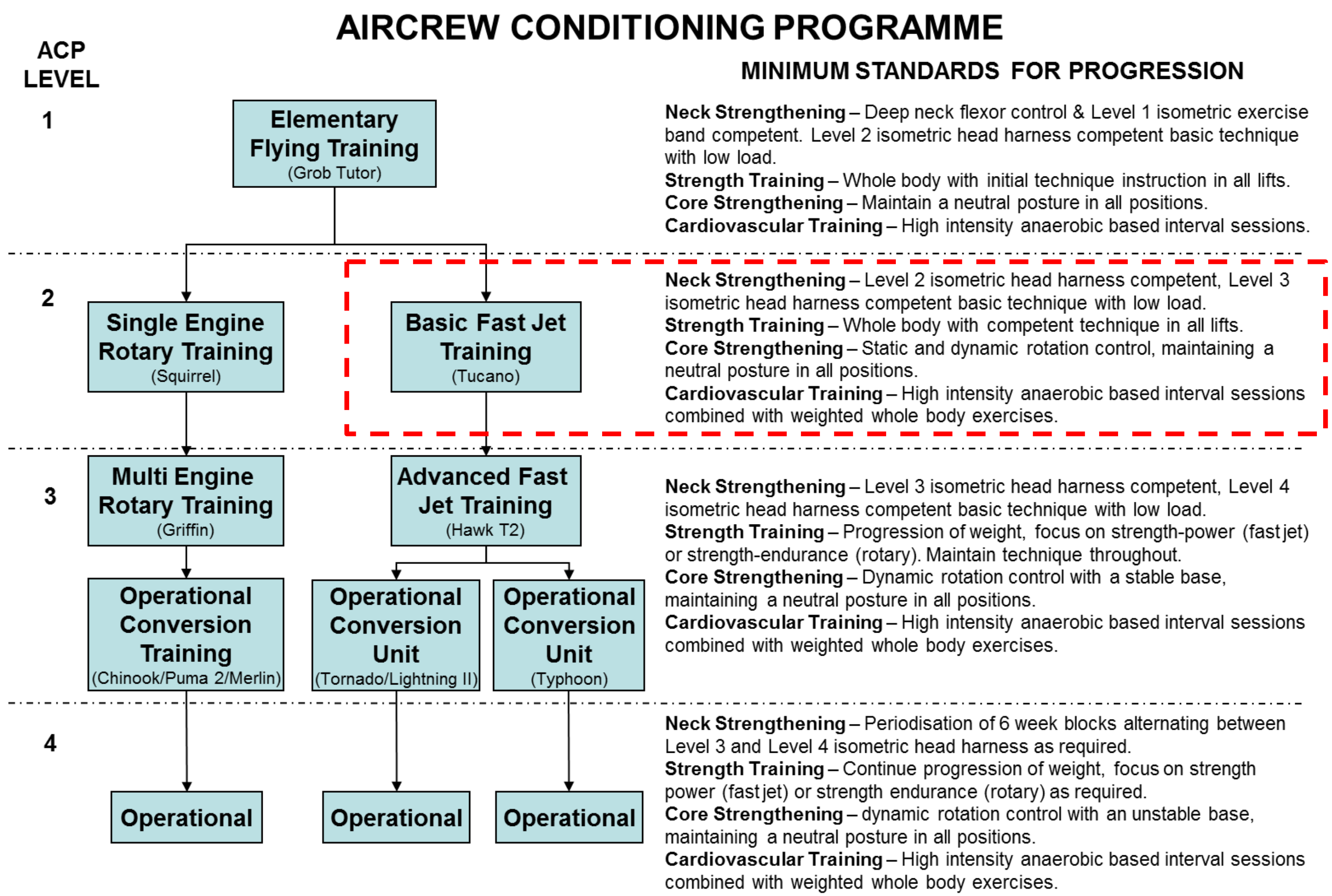

Figure 5.1 Aircrew Conditioning Programme (ACP) Delivery Flowchart. ACP Level 2 (area with red dashed box around) was reviewed by the panel of experts.

segmental stabilisers, with the load increasing only if a neutral position is maintained. Visual and verbal feedback is provided by the PTI/physiotherapist during the exercises.

5.3 Methods

5.3.1 ACP Development

The ACP underwent a two-stage process to assess content validity; a development stage and a judgement-quantification stage (Lynn 1986). Stage I consisted of a development stage with delivery at a number of RAF flying stations over a period of two years. At the end of this period, the ACP was reviewed and adjusted as a result of feedback received by all individuals involved (aircrew, PTIs and physiotherapists) in conjunction with the author, which led to the final ACP which was then assessed for Stage II (judgement-quantification) of content validation.

Level 2 of the ACP (Figure 5.1) was rated as it provides the basis for continuity and progression. This level was designed to be delivered to student aircrew at the second stage of flying training who had received basic instruction in cervical spine stabilisation exercises, core stability, and initial technique instruction for strength training exercises by a qualified PTI for a minimum of 12 sessions over a 6 week period. An overview of ACP Level 2 (Table 5.1) and a copy of the ACP Aircrew Aide-Memoire (Appendix 2) which was a booklet containing a description with pictures of all the exercises were provided to the expert reviewers. Levels 3 and 4 provide further progression of all the components with increased emphasis on whole body strengthening for fast-jet aircrew and rotational core control and flexibility for rotary aircrew.

Week	Session	ACP Components	
1	1	Deep neck flexor control and Level 1 isometric neck loading with elastic exercise band	1 Rep Max Test – Double leg press, flat barbell bench press, timed plank to failure
	2	Review deep neck flexor control and Level 1 isometric neck loading with elastic exercise band	Anaerobic Session – 10 x 300m row with 1 min recovery
2	3	Level 2A isometric neck loading with head harness (walking based exercises)	Strength Session – 4X5 Back Squat, Bench Press, Chin Up
	4	Level 2A isometric neck loading with head harness (walking based exercises)	Anaerobic Session – 400m running sprints (hanger runs) 1:1 Ratio work to rest, 8 efforts in total.
3	5	Level 2B isometric neck loading with head harness (kneeling based exercises)	Core Stability Session – Dynamic resistance to rotation on a stable platform
	6	Level 2B isometric neck loading with head harness (kneeling based exercises)	Anaerobic Session – Rowing (rest while partner works) 500m – 10 KB Swings – 10 Burpees, 400m – 12 KB Swings – 12 Burpees, 350m – 15 KB Swings – 15 Burpees, 250m – 18 KB Swings – 18 Burpees, 500m Row
4	7	Level 2A isometric neck loading with head harness (walking based exercises)	Core Stability Session – Dynamic resistance to rotation on a stable platform
	8	Strength Session – 4X5 Chin Up, Deadlift, Bench Press	Level 2A isometric neck loading with head harness (walking based exercises)
5	9	Level 2B isometric neck loading with head harness (kneeling based exercises)	Strength Session – 4X5 Deadlift, Bench Press, Front Squat
	10	Anaerobic Session – 21/15/9 reps, Dumbell Squat and Press, Chest to floor Burpees, Sit ups, Complete 21 reps on all 3 exercises, rest whilst partner works, drop reps on every rotation	Level 2B isometric neck loading with head harness (kneeling based exercises)
6	11	Introduce Level 3A isometric neck loading with head harness (whole body compound movements)	Anaerobic Session – interval rowing. Complete 1 Max Effort 100m on the minute, every minute. Complete 10 in total
	12	Level 3A isometric neck loading with head harness (whole body compound movements)	Core stability – Dynamic resistance to rotation on a stable platform
7	13	Introduce Level 3B isometric neck loading with head harness (sitting on exercise ball with arm movements)	Strength Session – 4X5 Push Press, Deadlift, Chin Up
	14	Level 3B isometric neck loading with head harness (sitting on exercise ball with arm movements)	Strength Session – 4X5 Deadlift, Bench Press, Back Squat

8	15	Level 3A isometric neck loading with head harness (whole body compound movements)	Anaerobic Session – spinning bike intervals Take resistance to a level you cannot move sat down, stand out of seat 15 s sprint from a standing start. 20 – 30 s rest, 15 mins in total
	16	Level 3A isometric neck loading with head harness (whole body compound movements)	Anaerobic Session – whole body weights with sprints 1X10 Kettlebell Swing, Burpees with Press Up, Deadlift with Powerbag, Sit Ups, Treadmill Run 400m, Complete one circuit then rest whilst partner works. Repeat 5 times through
9	17	Level 3B isometric neck loading with head harness (sitting on exercise ball with arm movements)	Strength Session - 4X5 Front Squat, Chin Up, Back Squat
	18	Level 3B isometric neck loading with head harness (sitting on exercise ball with arm movements)	Strength Session - 4X5 Chin Up, Deadlift, Bench Press
10	19	Anaerobic Session – interval sprints 2 min efforts at minimum of 15 kph, increase gradient by 2 on every effort. Working in pairs, 8 X 2 minute efforts each.	Level 3A isometric neck loading with head harness (whole body compound movements)
	20	Level 3B isometric neck loading with head harness (sitting on exercise ball with arm movements)	Anaerobic Session – 10 x 300m row with 1 min recovery
11	21	Strength Session - 4X5 Deadlift, Bench Press, Front Squat	Level 3B isometric neck loading with head harness (sitting on exercise ball with arm movements)
	22	Level 3A isometric neck loading with head harness (whole body compound movements)	Anaerobic Session – whole body weights with sprints 1X10 Kettlebell Swing, Burpees with Press Up, Deadlift with Powerbag, Sit Ups, Treadmill Run 400m. Complete one circuit then rest whilst partner works. Repeat 5 times through
12	23	Level 3A isometric neck loading with head harness (whole body compound movements)	Strength Session - 4X5 Push Press, Deadlift, Chin Up
	24	Level 3B isometric neck loading with head harness (sitting on exercise ball with arm movements)	Anaerobic Session – Run with Powerbag 300m, Kettlebell Turkish Getups 1X8, Powerbag Clean and Press 1X8, Kettlebell Swings 1X8, Powerbag Gun Drills 1X8, Kettlebell Around the Body 1X8, Run with Powerbag 300m, Repeat 3 times, rest whilst partner works

Table 5.1 Overview of Aircrew Conditioning Programme Level 2. Each session is supervised, lasting for one hour and is spilt into two parts.

5.3.2 Experts

A panel of 6 international independent experts were chosen for their expertise and availability and approached to participate. All had experience of either designing or delivering an exercise programme to aircrew, and all had doctoral degrees (4 physiotherapists, one physician and one kinesiologist). None were involved in the initial development and piloting of the ACP. All gave written informed consent before taking part, and confidentiality and the voluntary nature of the study were stressed.

5.3.3 Validity Assessment

Experts were asked to rate each item (individual exercise session or entire ACP) in terms of relevance and simplicity using a 4-point ordinal Likert rating scale (Lynn 1986) as follows; 1 – not relevant/not simple, 2 – somewhat relevant/exercise need some revision, 3 – quite relevant/clear but need minor revision, 4 – highly relevant/very simple (Walters et al. 2011). 'Not relevant' indicated that the individual exercise session/ACP was believed to be either of no benefit (or give no positive effects) in terms of treatment or prevention of spinal pain, or was not applicable to aircrew (Nilsson et al. 2011). 'Not simple' indicated that the individual exercise session/ACP was believed to be too difficult for the aircrew to accomplish (including home exercising), or for the physiotherapist/PTI to supervise the individual exercise session/ACP (including individual adjustment and progression) (Walters et al. 2011). Grades 3 and 4 were considered acceptable (Lynn 1986). A 4-point scale was used to avoid having a neutral and ambivalent midpoint.

Results were recorded in a standardised table. Item content validity index (I-CVI) was calculated for each item (24 exercise sessions) as the number of experts giving a rating of acceptable (score 3 or 4), divided by the total number of experts (Polit & Beck 2006). The criterion for item acceptability that incorporates the standard error of the proportion has been recommended as ≥ 0.83 for 6 experts (Lynn 1986). The I-CVI was then used to provide guidance with revising, deleting or substituting items within each ACP exercise session.

The scale-level CVI (S-CVI) was calculated based on the ratings of relevance and simplicity by the 6 experts, using the averaging approach (S-CVI/Ave) (Polit et al. 2007). It was calculated as the average proportion of items rated as 3 or 4 across the various experts. The lower limit of acceptability for S-CVI/Ave has been recommended as ≥ 0.90 for a scale to be judged as having excellent content validity (Polit et al. 2007).

Protocol-CVI was also calculated for the overall ACP using the same 4-point rating criterion as I-CVI. Experts were asked to rate the ACP against 5 questions; i) is the progression of exercises relevant and simple? ii) is the weekly supervision including instruction and manual guidance relevant and simple? iii) should the assigned exercises be conducted twice weekly? iv) can participants perform the ACP independently of any instructors, but within the gym? and v) is the aide-memoire with pictures illustrating the exercises given to the participants relevant and simple? The protocol-CVI was calculated for each question as the number of experts giving a rating of acceptable (score 3 or 4), divided by the total number of experts. For qualitative feedback the experts were also asked if any exercises should be either deleted or added to the protocol, with reasoning behind the decision.

5.4 Results

5.4.1 Item Content Validity Index (I-CVI)

The I-CVI of the individual exercise sessions was rated an excellent score for both relevance and simplicity for the majority of the exercise sessions. The relevance of 20 of the suggested exercise sessions reached an excellent I-CVI (1.00); with 4 items reaching acceptable I-CVI (0.83). For simplicity, 21 of 24 suggested exercise sessions reached an excellent I-CVI (1.00); the other three exercise sessions reaching acceptable I-CVI (0.83) (Table 5.2).

Four exercise sessions (1 - 4) were rated acceptable for relevance. These sessions included a review of exercises to activate the deep neck flexor muscles, progression onto activation of the global neck stabilising muscles, review of technique when performing global strength exercises e.g. squat and bench press, and some anaerobic interval sessions. One expert felt that the deep neck flexor exercises required greater supervision, with care not to progress the exercises too soon but if this was addressed the relevance and simplicity would be rated higher.

Exercise sessions 1, 2 and 11 were rated acceptable for simplicity. Session 11 (Table 5.1) involves progression of the neck exercises from level 2 (basic isometric neck exercises with a head harness) to level 3 (isometric neck exercises with a head harness combined with more complex movements of both the upper and lower limb), all whilst maintaining a neutral neck position under a low load. One expert liked the progression to the more complex exercise, but noted that these may be too challenging for some aircrew, with care required on progression.

Item	Number of Experts in Agreement	Item-CVI for Relevance		Item	Number of Experts in Agreement	Item-CVI for Simplicity
1	5	0.83		1	5	0.83
2	5	0.83		2	5	0.83
3	5	0.83		3	6	1
4	5	0.83		4	6	1
5	6	1		5	6	1
6	6	1		6	6	1
7	6	1		7	6	1
8	6	1		8	6	1
9	6	1		9	6	1
10	6	1		10	6	1
11	6	1		11	5	0.83
12	6	1		12	6	1
13	6	1		13	6	1
14	6	1		14	6	1
15	6	1		15	6	1
16	6	1		16	6	1
17	6	1		17	6	1
18	6	1		18	6	1
19	6	1		19	6	1
20	6	1		20	6	1
21	6	1		21	6	1
22	6	1		22	6	1
23	6	1		23	6	1
24	6	1		24	6	1
S-CVI/Ave for Relevance		0.97		**S-CVI/Ave for Simplicity**		0.98

Table 5.2 Item content validity index (I-CVI) rating results for relevance and simplicity for each item (24 exercise sessions) calculated as the number of experts giving a rating of acceptable (score 3 or 4), divided by the total number of experts (n = 6) (Polit & Beck 2006). The criterion for item acceptability that incorporates the standard error of the proportion has been recommended as ≥ 0.83 for 6 experts (Lynn 1986). Scale-level content validity index (S-CVI) was calculated based on the ratings of relevance and simplicity by the 6 experts, using the averaging approach (S-CVI/Ave). The lower limit of acceptability for S-CVI/Ave has been recommended as ≥ 0.90 for a scale to be judged as having excellent content validity (Polit et al. 2007).

5.4.2 Scale-Level Content Validity Index (S-CVI)

The scale-level CVI (S-CVI) calculated as the mean I-CVI (S-CVI/Ave) for all 6 experts across the suggested 24 exercise sessions was rated excellent for both relevance and simplicity (0.97 and 0.98 respectively) (Table 5.2).

5.4.3 Protocol Content Validity Index (Protocol-CVI)

The protocol-CVI for the ACP was rated good for relevance (0.90) and acceptable for simplicity (0.83) (Figure 5.2). A protocol-CVI of ≥ 0.90 has been recommended for a scale to have excellent content validity and 0.80 – 0.89 to be rated acceptable (Polit, Beck 2006). The ACP was rated excellent for relevance for the following; progression of exercises, weekly supervision and quality of the aide-memoire. It was rated acceptable for relevance for; ‘should the assigned exercise be conducted twice weekly?’, and fair for; ‘can participants perform the ACP independently of any instructors, but within the gym?’ One of the experts recommended that the exercises should be conducted on a more frequent basis and two felt that the aircrew should be closely monitored to encourage maximum adherence to the programme. The ACP was rated good (0.83) for simplicity for all the questions.

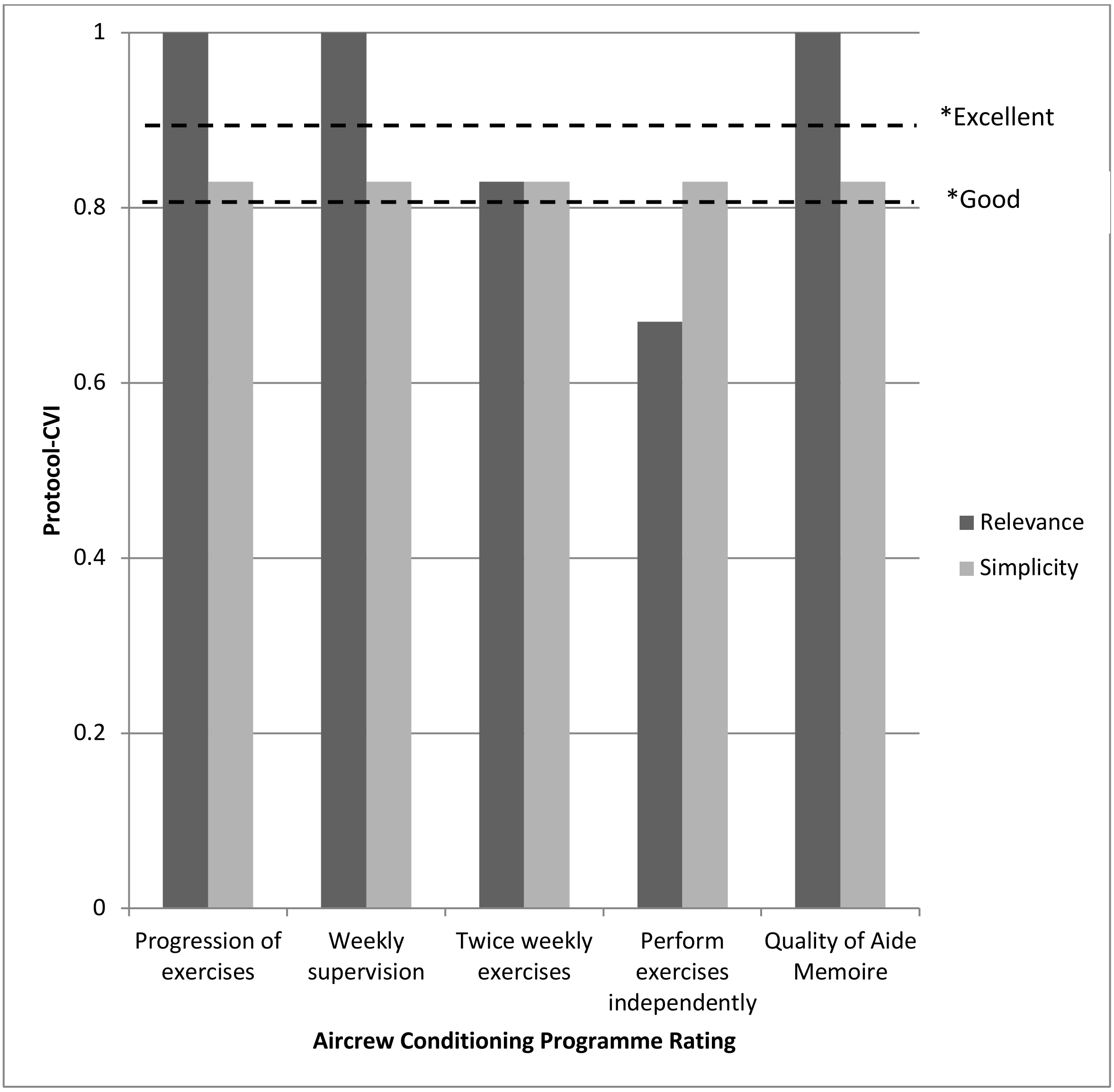

Figure 5.2 Protocol content validity index (protocol-CVI) was calculated for the overall Aircrew Conditioning Programme (ACP) (Level 2). Experts rated the ACP against 5 questions; i) is the progression of exercises relevant and simple? ii) is the weekly supervision including instruction and manual guidance relevant and simple? iii) should the assigned exercises be conducted twice weekly? iv) can participants perform the ACP independently of any instructors, but within the gym? v) is the aide-memoire with pictures illustrating the exercises given to the participants relevant and simple? The protocol-CVI was calculated for relevance and simplicity for each question as the number of experts giving a rating of acceptable (score 3 or 4), divided by the total number of experts. *Protocol-CVI was rated excellent (0.90) for relevance and good (0.83) for simplicity.

5.4.4 ACP Development

For completeness, the panel was also asked if any exercises should be deleted from or added to each individual exercise session or the overall ACP (Table 5.3). Three experts did not feel that any exercises should be deleted from the ACP, with one stating that all the exercises were appropriate and would be beneficial. One did feel that some of the initial head harness neck exercises could be improved. Also, there were contrasting views between the remaining two experts regarding the inclusion of front squats over back squats, with one preferring front squats to be optional for the aircrew, and the other preferring front squats over back squats due to the tendency for the load to be placed too high causing extreme forward position of the neck under load. A number of suggestions were made for additional exercises to be added to the ACP; pre-flight neck isometrics to compliment the dynamic neck stretches; a kettlebell session based around functional movement; fast and varied arm movements whilst maintaining a neutral neck position to increase dynamic control; more frequent core stability exercises; and controlled dynamic low load tasks. Care on progression and supervision of early deep neck flexor and core work was also recommended, although an expert did note that the ACP was very comprehensive.

Expert	**Should any exercise(s) be deleted from the protocol?**	**Should any exercise(s) be added to the protocol?**
1	Front squatting is questionable, it could be optional	Pre-flight neck isometrics (against hand) could compliment dynamic neck stretches.
2	Neck strengthening 2B seem unnecessary. Could there be an alternative progression as this seems difficult to grasp and appears to be not as functional as the rest of the programme.	Perhaps a kettlebell session based around functional movement.
3	No, all exercises seem relevant and well placed	Neck strengthening progression very much seems to be based on progressive weight loading, but fast and varied arm movements might also be relevant whilst maintaining neutral neck position. This might be functionally relevant and increase dynamic control. Care on early deep neck flexor and core work.
4	Overall looks a great programme. Really my main area would be looking at the neck and core, and these exercises do look great. Given the history of low back pain and the current recommendation for core exercise, would it be possible to make these more frequent in the programme?	Have you considered some controlled dynamic low load tasks?
5	Congratulation on putting together the Cadillac of exercise programmes. I do not have any specific comments – the exercises are all appropriate and would be beneficial.	My concerns relate to the level of detail and length of the programme. Aircrew may not fully adhere to the programme because of the volume and detail.
6	I'm not a huge fan of back squats generally because of the tendency for the load to be placed too high causing extreme forward positioning of the neck under load. Front squats are my preference because of this.	Very comprehensive program.

Table 5.3 Suggestions by the panel of experts of which exercises should be deleted/added to the protocol (Aircrew Conditioning Programme).

5.5 Discussion

The ACP demonstrated excellent content validity for the individual exercise sessions (I-CVI) and for the overall programme (protocol-CVI) in terms of relevance and simplicity for delivery to the aircrew population. Of the 24 exercise sessions, 20 were rated excellent (I-CVI 1.00) for relevance and 21 were rated excellent (I-CVI 1.00) for simplicity. The remaining exercise sessions were rated acceptable (I-CVI 0.83) for relevance and simplicity. S-CVI/Ave reached 0.97 for relevance and 0.98 for simplicity, and was higher than the recommended 0.90 (Polit & Beck 2006).

CVI is an index of interrater agreement that simply expresses the proportion of agreement, and the possibility of agreement can be inflated by chance (Polit & Beck 2006). For Stage II, the judgement-quantification stage, a minimum of five experts has been recommended, providing sufficient control for chance agreement (Lynn 1986). A criteria has also been developed for item acceptability that incorporates the standard error of the proportion (Lynn 1986), recommending that when there are 6 or more judges, the I-CVI should be no lower than 0.83 for the rating to be assessed content valid (Lynn 1986). This allows for one 'not relevant' rating with six judges.

The ACP exercise sessions which were rated as acceptable for relevance to the aircrew were sessions 1 – 4, with three sessions (1, 2 and 11) scored as acceptable for simplicity. Sessions 1 – 4 involve a review of the basic neck exercises (level 1) which includes activation of the deep neck flexor muscles, progressing to the initial isometric neck exercises using a head harness attached to a weighted pulley system in a standing position. For all of these exercises, the aircrew are advised to maintain a neutral head posture. The panel commented that increased supervision was required for the aircrew during these early sessions, to ensure effective activation of the deep neck flexor muscles prior to progression with increased load and limb motions. Exercise session 11 involved progression of the neck exercises to more complex isometric loading of the neck in a neutral position in a standing and sitting position. These exercises combine low loading of the neck muscles with complex whole-body movements with an emphasis on either strength-endurance (squat, lunge, trunk side bend) or strength-stability (sitting on an exercise ball maintaining a neutral spine whilst moving the upper limb with resistance) (Figure 5.1). Again, the panel felt that as these were complex movements requiring a relatively high degree of skill, there should be suitable supervision of the aircrew by the PTI/physiotherapist during this session. The ACP exercise sessions have now been adjusted to include greater supervision with the inclusion of an additional PTI during all the sessions highlighted.

The original design of the ACP was centred on a neck and shoulder exercise programme that had been shown to be effective in reducing neck pain in air force helicopter pilots (Ang et al. 2009), which involved physiotherapist supervised exercise sessions progressing from non-postural to postural load-situated exercises, moving largely from isolated low-load muscle exercises to synergy endurance-strength exercises (Ang et al. 2009). The non-postural exercises incorporated activation of the cervical spine deep postural muscles and scapular muscles, progressing to activation of the same muscles in a sitting posture. The endurance-strength exercises involved dynamic shoulder retraction and dynamic neck rotation exercises using an elastic exercise band, maintaining activation of the deep cervical muscles throughout (Ang et al. 2009). During the development phase of the ACP, this exercise programme was delivered to aircrew flying a high +Gz capable aircraft. Unfortunately, the feedback from the aircrew was that the exercises, whilst improving neck symptoms when sat in the office, made little or no difference to the neck pain reported during the +9 Gz air-combat sorties. As a result of this feedback, additional neck exercises were added to the ACP.

The neck exercise component of the ACP now follows a coordinated training programme with focus on activation of the deep segmental cervical stabilisers (deep neck flexor muscles) in a neutral standing position prior to the addition of limb motion and loading of the superficial prime movers. This follows the principles recommended by Ang et al (Ang et al. 2009) and Salmon et al (Salmon et al. 2013) who both described an exercise programme for improving neck muscle function in helicopter aircrew with neck pain. Whole body motor control exercises are also advised for all ACP levels to improve movement quality and maintain posture (Hides et al. 2017).

Increased neck muscle strength has been suggested to protect and stabilise the head and neck during brief episodes of increased loading as a result of +Gz (Ang et al. 2005), and a targeted deep neck muscle training programme combined with neck and shoulder strength training proved effective in reducing neck pain in F-16 pilots (Lange et al. 2013). Loading of the cervical muscles to 50% of the maximum voluntary isometric contraction has been shown to mimic the neck loads experienced during +5 Gz, suggesting that fast-jet aircrew should strengthen their necks to withstand these loads during air-combat sorties (Netto et al. 2007).

As part of the ACP following effective activation of the deep neck flexor muscles, aircrew progress to isometric loading of the neck in a neutral position using a head harness attached to a weighted pulley system, initially in a standing position, eventually progressing to a sitting position. These exercises are based on a progressive and supervised isometric neck strengthening program which reported a significant decrease in match-related cervical spine injuries in a men's professional rugby union team (Naish et al. 2013). This exercise programme involved isometric loading of the neck in a neutral position using a head harness attached to a weighted pulley system cable into flexion, extension, lateral flexion and 45 degree neck flexion to the left and right. Players completed a 13 week strengthening phase followed by a 13 week maintenance phase with any asymmetries identified on baseline strength testing addressed. Variations of these exercises were added to the ACP but aircrew were not progressed to them until they had sufficient control of the deep cervical muscles (Figure 5.1).

For protocol-CVI the experts rated the ACP for relevance and simplicity against a series of questions (Figure 5.2). Four of them rated the ACP excellent for relevance for all of the questions. However, one commented that the exercises should be completed more frequently and two felt that the ACP required greater supervision particularly during the neck exercises and the control exercises. For simplicity 5 of the experts rated the ACP excellent for all the questions and one expert consistently rated the exercises as needing some revision to improve the simplicity. The expert commented that the ACP was too ambitious and preferred for the aircrew to concentrate on a few key exercises that could be implemented into their own training habits and completed more frequently.

The panel of experts were asked if any of the exercises should be either deleted from or added to the ACP, with reasons given (Table 5.3). The majority of them commented that the exercises were relevant, appropriate and beneficial. There were mixed views regarding the inclusion of front squats over back squats but it was felt that with appropriate instruction both exercises were safe and appropriate for the aircrew.

A number of suggestions were made for inclusion into the ACP. Pre-flight neck exercises will now be added to the pre-flight stretching exercises. A kettlebell session based around functional movement patterns has also been added to the new ACP based on this study. As discussed earlier, all the experts recommended the need for sufficient supervision during the exercises both from a safe exercise execution and to maintain aircrew adherence to the ACP. This is in line with previous exercise programmes designed for aircrew (Ang et al. 2009, Salmon et al. 2013) and astronauts (Lambrecht et al. 2017), and an additional PTI will now supervise the highlighted sessions. Whilst the quality of the supervision of the ACP exercise sessions has not been directly measured, it is noted that this is a fundamental aspect of the success or failure of the ACP. Prior to delivery of any exercise session, all PTIs must complete and pass a 5 day course covering all aspects of the ACP exercise sessions. PTIs are then advised to monitor aircrew technique during the exercises, provide coaching points as required and adjust the exercises to meet the needs of the individual. The PTIs and physiotherapists work with the aircrew during the exercises sessions with an aim of building strong therapeutic alliances to promote improved exercise adherence (Stokes, Evetts et al. 2017). Once aircrew are competent in the exercises, they are encouraged to continue with them independently as part of their normal weekly exercise routine, with adherence reviewed 6 months following the end of the supervised sessions. Adherence to these exercises away from supervision will be reviewed as part of a further study.

A limitation of the study is that the quality of the written material sent to the experts may have hindered understanding of the practical nature of the exercises and supervision provided by the PTIs and physiotherapists.

5.6 Conclusion

The ACP has demonstrated excellent content validity for use with an aircrew population and for delivery by a team of trained PTIs and physiotherapists. The aircrew require additional supervision with the exercises to enhance simplicity with the ACP. Whilst it is comprehensive in its detail, all the exercises are relevant to the population and the demanding environment they work in.

Having established the content validity of the ACP, the next phase of this work was to establish its efficacy. The effect of the ACP on physiological performance in a high +Gz environment will now be investigated.

Chapter 6 The effects of the Aircrew Conditioning Programme on Physiological Performance in a High +Gz Environment

6.1 Introduction

As has already been described in this thesis there are considerable physical challenges to the +Gz environment and physical conditioning may be an effective modality for increasing the ability of aviators to operate in a high +Gz environment. To date yet few studies have investigated the efficacy of improving physical fitness on +Gz performance (Bateman et al. 2006). Operating in this unique environment requires aircrew to be able to repeatedly perform an effective AGSM during periods of high +Gz, and be able to move and look out of the cockpit. The AGSM requires muscle contraction in order to increase systemic BP and increases in muscle strength brought about by training may result in a reduced relative effort required to elicit the BP increase needed to tolerate a given +Gz stress (Bateman et al. 2006).

Existing research has not clearly demonstrated whether strength training affects +Gz tolerance. Improvements in strength or endurance (or both) of the large muscle groups recruited during the AGSM might enhance +Gz tolerance if fatigue of these muscles were a limiting factor in SACM tolerance time. There could also be indirect strength training effects on +Gz tolerance, mediated through established effects on respiratory muscles, blood pressure or both (Bateman et al. 2006). It should be noted that excessive aerobic fitness may reduce +Gz tolerance by decreasing arterial stiffness (Otsuki et al. 2007) and alter the balance between sympathetic and parasympathetic activity (Green 2006b). With this in mind a conditioning programme has been designed and subjected to construct validity (Chapter 5).

As already discussed in this thesis, an individual's +Gz tolerance can be determined in different ways. As the highest +Gz load (+Gz-level tolerance) attained without G-LOC (Burton 2000b) or as the amount of time sustained under a single exposure of increased +Gz (+Gz-duration) (Burton 2000a). The tolerance limit in +Gz-duration is defined as the development of a recognisable level of subjective fatigue (Burton 2000a). +Gz-level tolerance can be measured with the individual remaining relaxed (relaxed +Gz tolerance – RGT) or straining as when performing the AGSM, or tensing only the muscles of the lower limb and abdominals. In a controlled experimental setting, +Gz-duration tolerance is examined using a model of +Gz stress, usually in the form of SACM profiles on a centrifuge, to an endpoint such as limit of volitional tolerance or visual loss.

Having established the Aircrew Conditioning Programme its efficacy in regard to +Gz tolerance now needs to be objectively determined. Thus, the aim of the work outlined in this chapter is to measure the effect of the ACP performed for 12 weeks on i) relaxed and straining +Gz-level tolerance (SGT), ii) +Gz-duration tolerance to repeated high sustained +Gz during a series of SACM profile centrifuge runs iii) associated physiological parameters, in order to determine whether the ACP would have a beneficial effect on aircrew performance in a controlled high +Gz environment.

6.2 Methods

6.2.1 Participants

All RAF and Royal Naval (RN) aircrew enrolled on the Elementary Flying Training (EFT) and Basic Fast-Jet Training (BFJT) courses were invited to participate in the study. Inclusion criteria were aged > 35 years, had an aircrew medical in the last 12 months including a 12-lead ECG and be in-date for the RAF or RN Fitness Test. These involve completion of a minimum of 20 press-ups and 35 sit-ups both within one minute, and reaching a minimum of level 9.10 in the 20 m shuttle run test or multi-stage fitness test (Mayorga-Vega et al. 2015). Attainment of these levels results in a 6 month validity of fitness. All participants were required to undertake centrifuge training as part of aircrew training prior to recruitment, which included similar +Gz levels/profiles to those included in this study. Subjects were excluded if they had any temporary or permanent limitations on their Medical Employment Standard.

The protocol was approved by the RAF Experimental Medicine Scientific Advisory Committee and the Ministry of Defence Research Ethics Committee (Ref: 523/MODREC/14) (Appendix 3).

All subjects provided written informed consent following issue of an information sheet (Appendix 4), and completed a Health Screen for Study Volunteers (Appendix 5). A weekly activity log covering a 12 week period was also issued which recorded performance of exercise, non-aviation related incidents associated with neck pain/spinal pain (athletic, non-work related, sleeping), flight hours with and without night vision goggles and basic fighter manoeuvre (BFM)/air combat manoeuvre (ACM) sorties, subjective level of maximum and average neck pain, and any treatment received (Appendix 6).

Due to the nature of UK flying training and access to an appropriate aircrew subject pool the study could not be blinded or randomised. Subjects who were enrolled on the EFT course were preselected into Group 1 (Control) and subjects enrolled on the BFJT course were preselected into Group 2 (ACP). Every effort was made to match the physical stature of the two groups through selection of only aircrew. All subjects had been deemed suitable for RAF/RN flying training and had passed the anthropometric criteria for aircrew selection. Whilst every effort was made to recruit females into the study, there were none enrolled in either EFT or BFJT during the recruitment phase of this study.

6.2.2 Testing +Gz Tolerance

6.2.2.1 *Equipment and Experimental Setup*

The QinetiQ human centrifuge in Farnborough was used to simulate the high +Gz environment. Accelerations could be produced in a controlled and reproducible manner, with adequate provision for instrumentation. The centrifuge (Figure 6.1) consists of two rotating arms (radius 9.1 m) with free swinging gondolas at each end. The rotating mass is 44 tonnes to include the arm, gondolas and flywheel. A 1,400 horsepower (1.044 megawatts) motor, vertically below and directly coupled to the arm provides the motive force. Reversing the electromagnetic field slows the centrifuge. A series of hydraulic drum brakes are employed to bring the centrifuge to an absolute standstill and for emergencies. A maximum acceleration onset rate of ≤ 1 $G.s^{-1}$ can be generated due to its age (commissioned in 1955), up to a maximum plateau acceleration of +9 Gz. The gondolas are provided with lighting, mains electrical (240v AC) and gas (2700 kPa breathing air) services. Additionally, a number of instrumentation lines are available (via slip rings) to connect gondola measuring equipment to recording systems located remotely in the building.

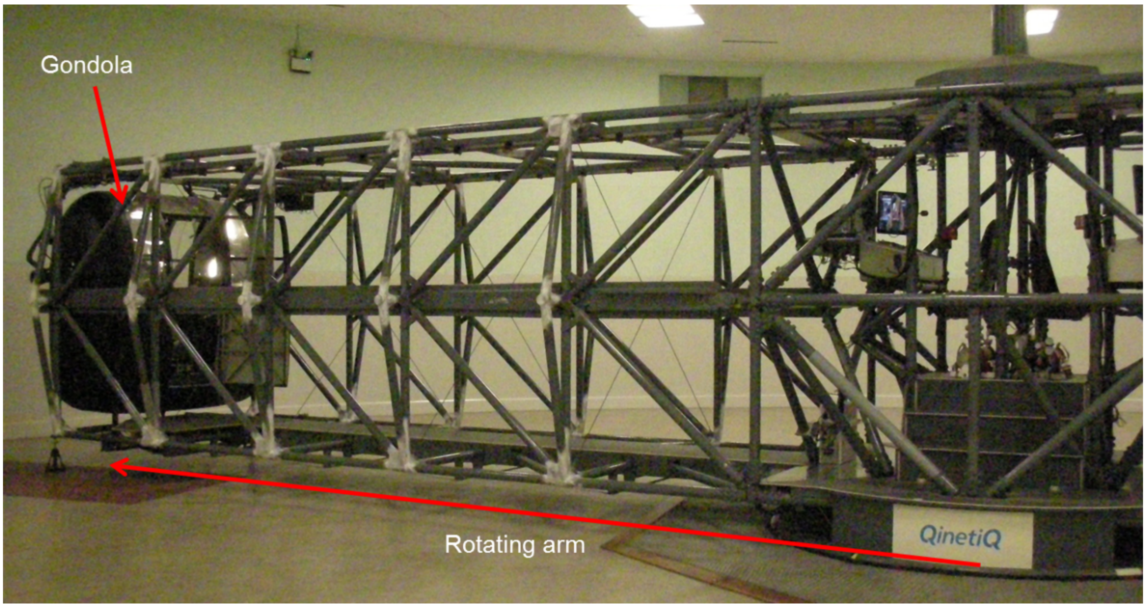

Figure 6.1 The QinetiQ human centrifuge (Farnborough, UK).

+Gz acceleration was measured using a servo-accelerometer (Lucas Schaevitz, Pennsauken, NJ, USA) positioned at the roll-axis of the gondola, which was at the level of the subject's chest (~ mid sternum). Monitoring of the experimental subject was conducted by a medical officer seated at the centre of rotation of the arm, via closed circuit video and audio. Body mass, size and balance constraints limit the installation of measuring equipment in the gondola, and equipment must be capable of operating normally under high +Gz loads. The centrifuge gondola was configured to be ergonomically representative of the Typhoon cockpit and subjects were harnessed into an ejection seat (Mk 16, Martin Baker Aircraft Company Ltd, Higher Denham, Middlesex, UK) (Figure 6.2). The chamber containing the centrifuge is maintained at a temperature of 18° C (± 2° C).

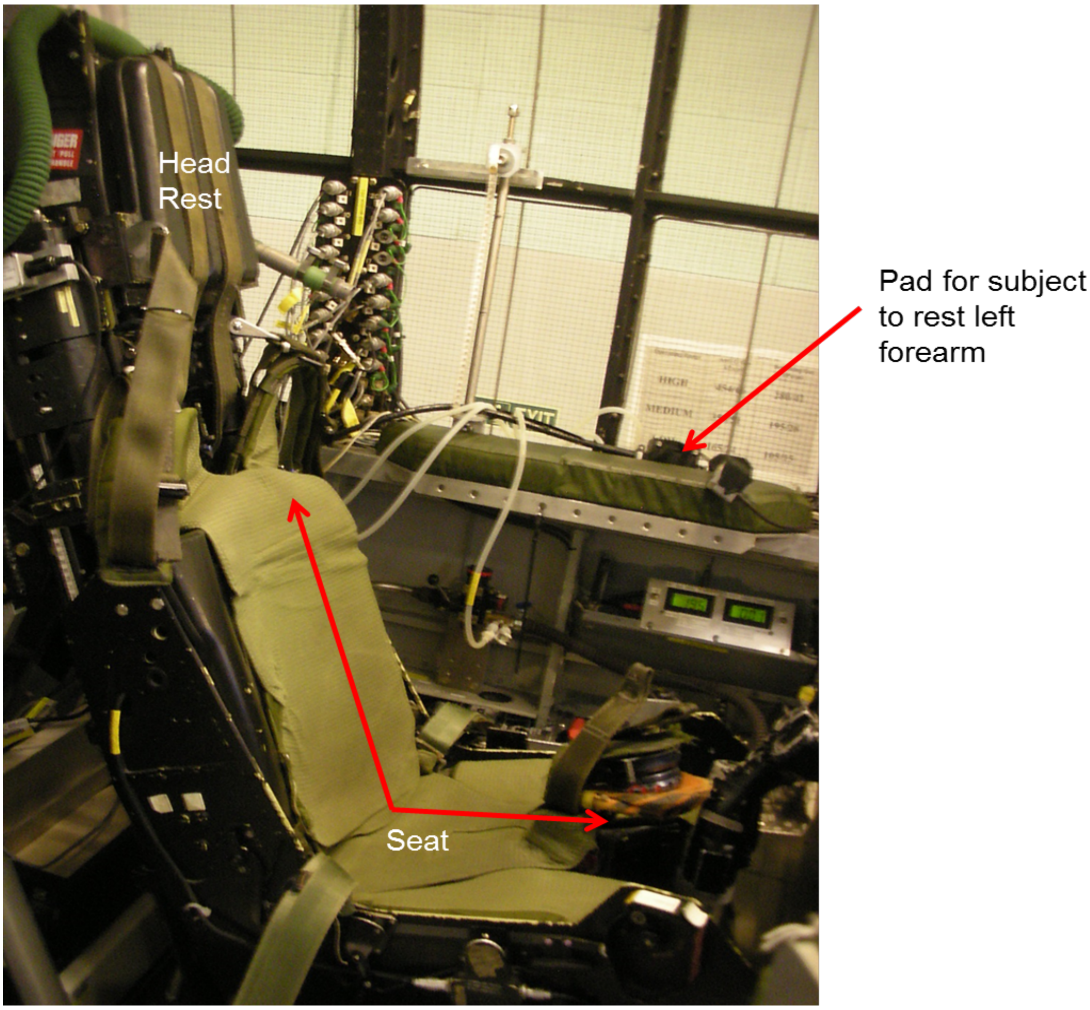

Figure 6.2 Mk 16 ejection seat positioned inside one of the centrifuge gondolas.

A consequence of the short radius of turn within the centrifuge is the production of disorientating, and at times nauseating, vestibular illusions during deceleration. Adaption to these illusions occurs with regular exposure, but the disorientation combined with the strong nystagmus can produce extreme nausea in some subjects, which may prevent further experimentation.

Subjects were dressed in a standard issue RAF flying coverall, aircrew boots, a Mk10R helmet and an RAF type P/Q oronasal mask. The P/Q mask provided communication and was used to aid collection of expired gas which will be discussed in greatly detail later. They wore standard 5 bladder anti-G trousers (Mk4) and inflatable foot bladders pressurised by a Hawk anti-G valve (VAS 110-022, Hymatic Ltd, Redditch, UK) installed in the centrifuge gondola. Anti-G trouser (AGT) pressure was monitored from a tapping in the AGT hose throughout the centrifuge exposures using piezoresitive pressure transducers (Kistler Instruments AG, Winterhur, Switzerland) calibrated to a reference manometer daily.

6.2.3 Experimental Protocol

The subjects undertook a number of exposures to +Gz acceleration seated in the gondola of the QinetiQ human centrifuge. The testing protocol on each occasion comprised of three different components which will now be described followed by how the subjects were instrumented.

6.2.3.1 *Relaxed +Gz Tolerance*

The first two runs measured the subjects relaxed +Gz tolerance (RGT) using a standardised test protocol (Scott et al. 2013). This involved completing two consecutive, gradual onset rate +Gz acceleration runs (0.1 $G.s^{-1}$) separated by a 2 min rest period (Figure 6.3), with each exposure terminated by the subject at the point of 60° peripheral visual loss. RGT for each subject was taken as the mean value from both runs. Personal protective clothing was worn but the regulator supplying pressurised gas to the AGT was disabled.

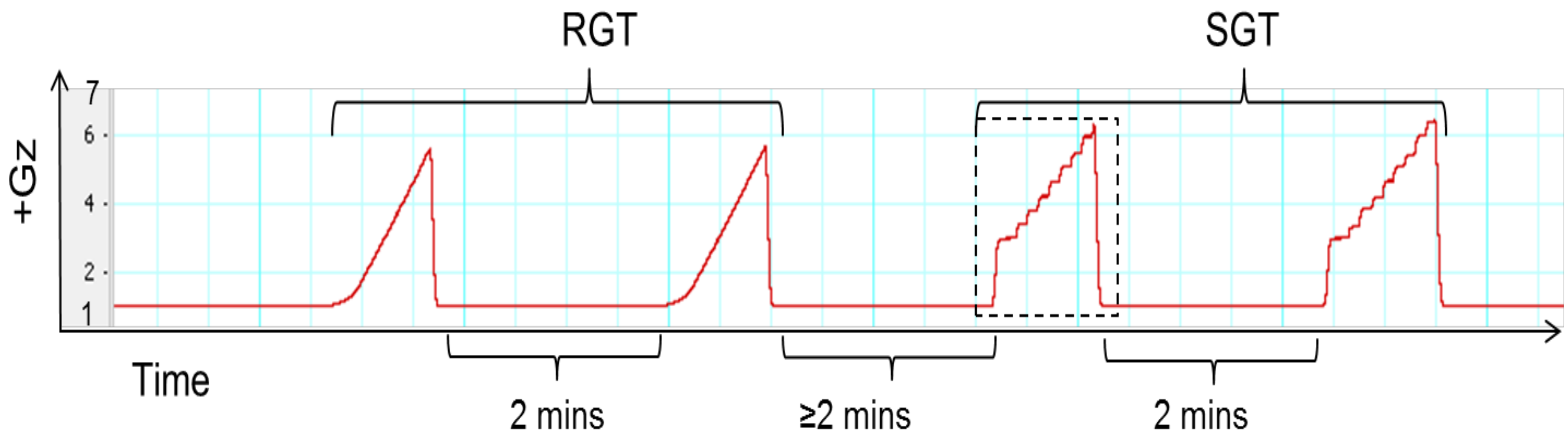

Figure 6.3 Schedule for the +Gz exposure runs with two runs to measure both relaxed +Gz tolerance (RGT) and straining +Gz tolerance (SGT). Dashed box around first SGT run is shown in greater detail in the following Figure 6.4. Each run was separated by a 2 min rest period. Heart rate was measured continuously during the runs.

6.2.3.2 *Straining +Gz Tolerance*

Straining +Gz tolerance (SGT) was then measured on the centrifuge. This consisted of a stepped protocol from +3 Gz (for 15 s), increasing every 5 s thereafter in +0.5 Gz increments up to +7 Gz or when terminated by the subject (Figure 6.3). Changes in acceleration were achieved at an onset rate of 1 $G.s^{-1}$. Subjects were instructed to remain relaxed until they had to intervene (subjects tracked their visual symptoms to a pre-determined point of 60° peripheral visual loss) and thereafter strain by tensing only the leg and abdominal muscles (i.e. no breathing manoeuvre) as needed to maintain clear vision. Subjects terminated the run when they are unable to maintain clear vision through straining and this +Gz level indicated their straining +Gz tolerance. Subjects completed two runs with the better of the two +Gz levels obtained used in subsequent analysis. As above the anti-G valve was disabled during these runs. Further analysis was undertaken for all subjects who reached the +5.5 Gz step (Figure 6.4) and will be discussed in greater detail in the Results section.

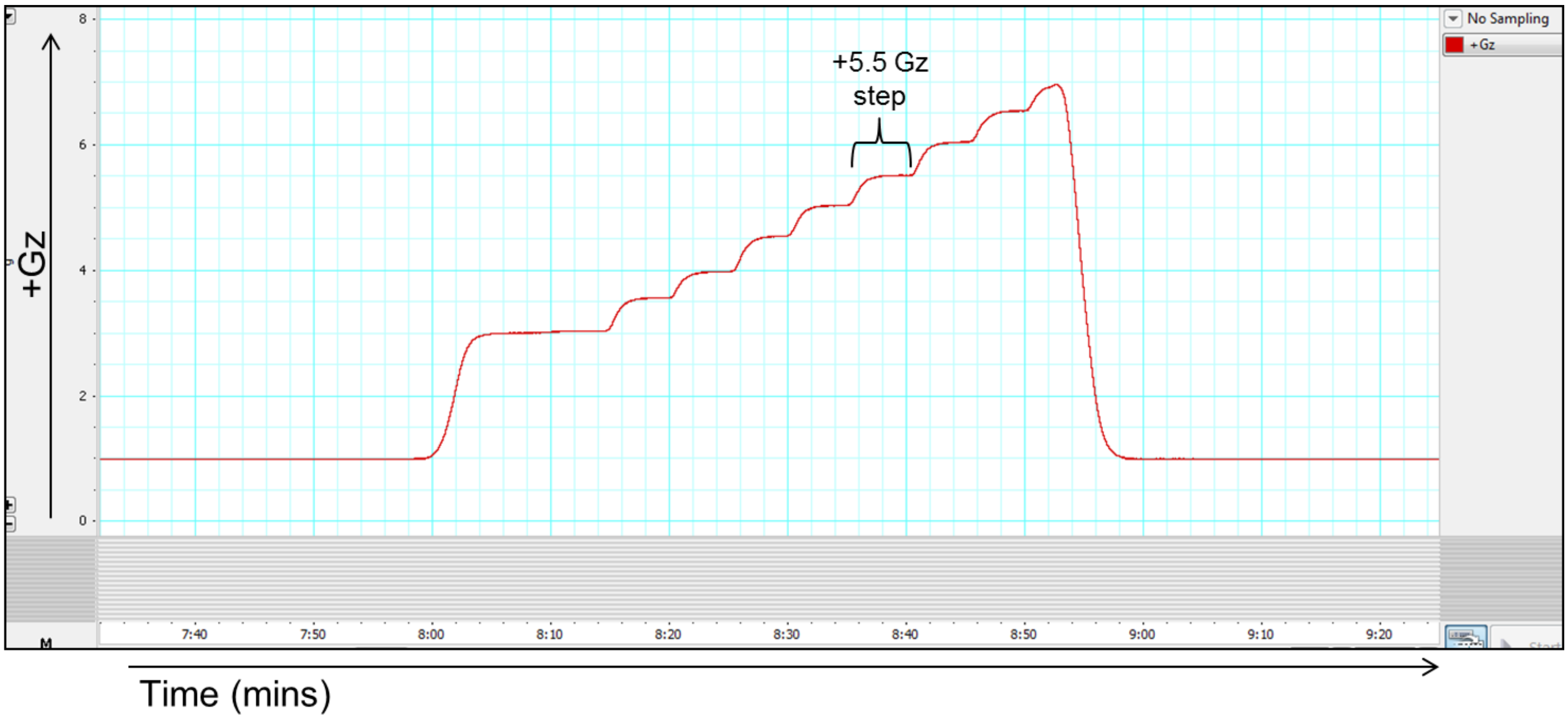

Figure 6.4 Schedule for one of the SGT runs with the +5.5 Gz step indicated. Each run was separated by a 2 min rest period. Heart rate was measured continuously during the runs.

6.2.3.3 *Simulated Air Combat Manoeuvres*

Subjects then completed 4 SACMs with consecutive exposures separated by 2 min rest periods. Each SACM consisted of 4 cycles of 5 s at +7 Gz followed by 15 s at +5 Gz at an on/offset rate of 1 $G.s^{-1}$ (Figure 6.5). Subjects were advised to perform the AGSM as required to maintain clear vision and to terminate the run if they reached the point of volitional exhaustion or if they could no longer maintain clear vision, despite maximal physical effort. For this phase the anti-G valve was enabled. Whilst all measurements were recorded throughout the SACMs, data recorded during the first and fourth +7 Gz peak was used for subsequent analysis. The first peak was used as participants are required to perform a maximum AGSM to maintain head-level BP. The cardiac baroreceptor response provides a recovery in head-level BP 6-12 s after the onset of acceleration exposure (Wood et al. 1989), which coincides with the second +7 Gz peak. Figure 6.6 shows one SACM in greater detail with the first and fourth +7 Gz peak highlighted with a dashed box.

HR, foot pedal force, and EMG of lower limb muscles were measured continuously during the runs. Rating of perceived exertion (RPE) was recorded after each SACM using the BORG category-ratio scale (CR-10) (Borg et al. 1985). Recovery HR was recorded for 1 min immediately after completion of SACM 4. Post acceleration O_2 composition was collected using a Douglas bag for 2 min after SACM 2 and SACM 4. A finger prick blood sample was collected approximately 180 s after the end of SACM 4 (or after the point of voluntary termination by the subject). Five min after completion of all the centrifuge runs, the subjects repeated the procedure to maintain 30% of the maximum leg push force. Subjects were asked to sustain this pressure for as long as possible, terminating when they could not maintain this level any longer. The primary outcome measure was the duration of exposure tolerated during repeated SACMs.

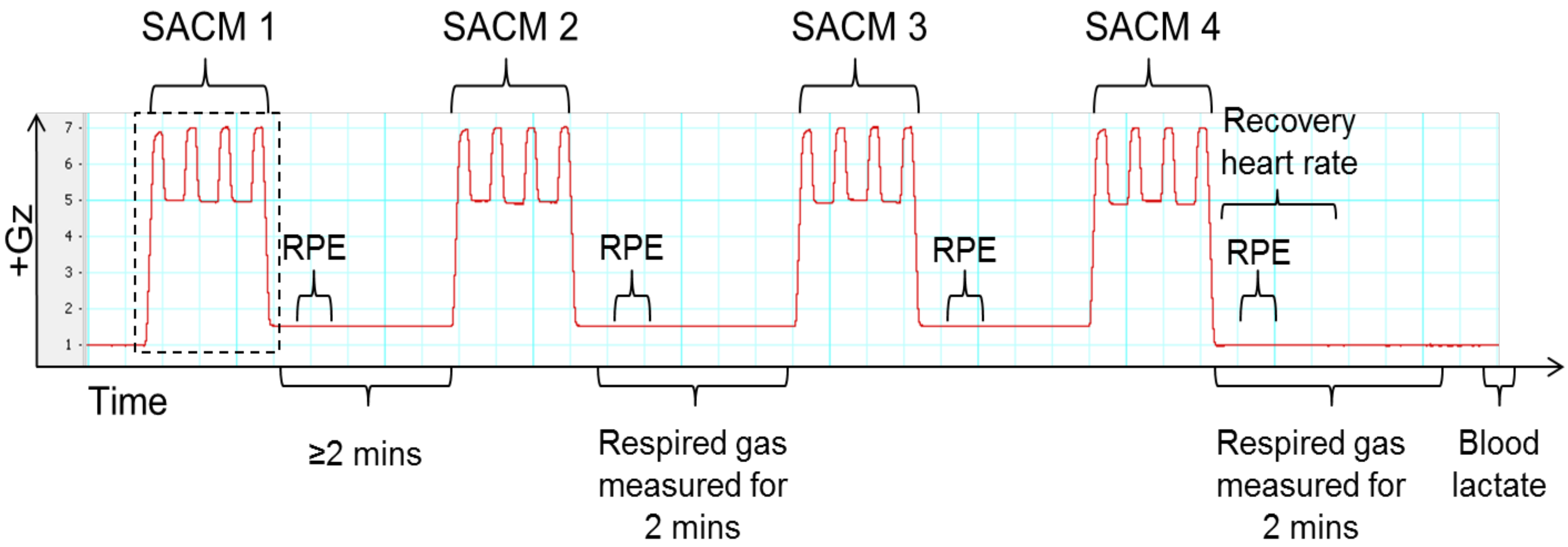

Figure 6.5 Schedule for the 4 high and low intensity +Gz exposure SACM runs (5 s at +7 Gz followed by 15 s at +5 Gz at an on/offset rate of 1 $G.s^{-1}$) with each run separated by a 2 min rest period. The dashed box around SACM 1 is shown in greater detail in Figure 6.6.

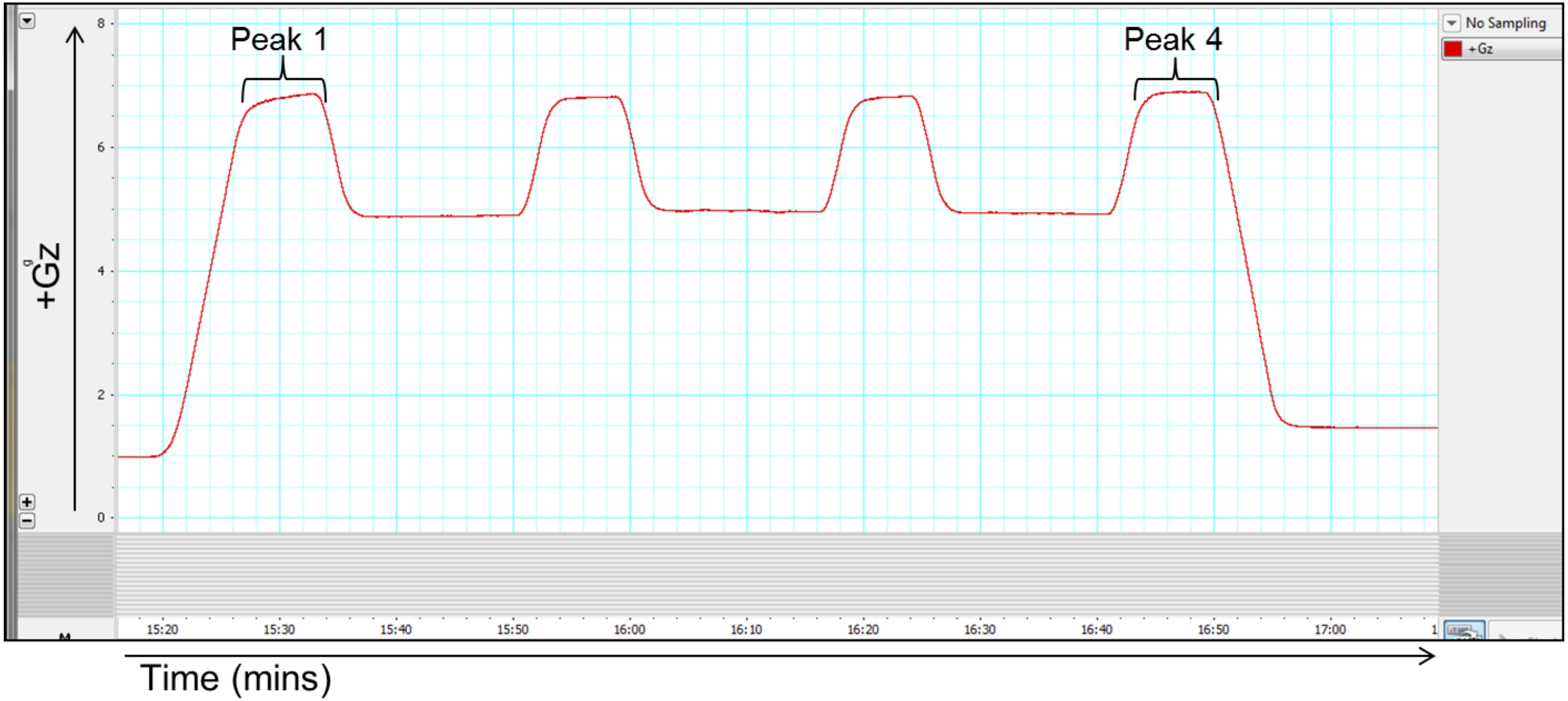

Figure 6.6 Schedule for one SACM run (5 s at +7 Gz followed by 15 s at +5 Gz at an on/offset rate of 1 $G.s^{-1}$). The first and fourth +7 Gz peak is indicated. Heart rate, foot pedal force, and EMG of lower limb muscles were measured continuously during the run. Rating of perceived exertion (RPE) was recorded after each SACM

6.2.4 Initial Measurements

Prior to and during the centrifuge runs, a number of physiological measures were taken.

6.2.4.1 *Heart Rate*

Resting heart rate (HR) was derived from a three-lead electrocardiogram (ECG) (FE-262-B1/A-1 Isolation Amplifier, Fylde Electronics Laboratories, Preston, UK) positioned on the thorax following 4 min of the subject lying supine. HR was monitored throughout all the centrifuge exposures and for two min following the final run. The HR response during the RGT centrifuge runs was calculated as the slope of the linear regression between HR and acceleration ($\Delta HR.G^{-1}$). During the SGT runs HR was averaged over the last two s of each plateau in order to capture the greatest effect of each +Gz plateau. The maximum HR was recorded during each SACM and recovery HR was determined as the mean during the immediate 60 s period post SACM.

6.2.4.2 *Blood Pressure*

Resting blood pressure (BP) was recorded with a non-invasive BP cuff (IntelliSense 705IT, Omron®, Milton Keynes, UK) around the left arm following 4 min of supine lying. During the centrifuge exposures, beat-to-beat non-invasive BP was continuously recorded with the Finapres™ 2300 (Englewood, Denver, CO) during all the centrifuge exposures. This was because the traditional clinical method (Riva-Rocci method) was considered too slow, particularly as the changes in vascular pressure in the arm occur almost instantaneously of applied acceleration. The Finapres™ measures BP using the volume-clamp method (Penaz, 1973). Changes in the diameter of a digital artery detected by an infra-red photoplethysmograph are kept constant by changing the pressure in a surrounding cuff, by a fast responding pressure servo controller (~ 10 milliseconds). An increase in arterial diameter causes more light to be absorbed, resulting in a reduced light signal detected by the photoplethysmograph. The pressure in the cuff increases and decreases with rises and falls in blood pressure to maintain a constant blood volume. Accurate measurement requires that the measured artery's unloaded diameter be determined first, which is the point at which cuff pressure and intra-arterial mean pressure are approximately equal and diameter changes will be largest. The unloaded diameter is determined via a calibration procedure (Physiocal™) in which a number of stepped inflations then deflations establish the maximal amplitude of the photoplethysmograph signal. This forms the set-point and the cuff pressure oscillates above and below this value in direct concordance with arterial blood pressure (Boehmer, 1987). The Physiocal™ procedure occurs at intervals of throughout measurement to reconfirm the unloaded diameter of the artery, which leads to a loss of signal.

The Finapres™ has been validated under +Gz acceleration conditions by McKenzie (McKenzie, 1991) on the Farnborough centrifuge. The Finapres™ was compared to intra-arterial radial artery pressure recorded in the contralateral arm, with the arms positioned at heart level. It was found that Finapres™ slightly underestimated systolic and diastolic pressures (systolic = 8 mmHg, diastolic = 9 mmHg) but this error was unaffected by +Gz.

6.2.4.3 *Rest and Post Acceleration O_2 Composition*

The volume and rate of respired gas composition was measured using the Douglas Bag method. The following were calculated from the expirate:

Volume of oxygen ($\dot{V}O_2$):

Equation 4

$$\dot{V}O_2 = \left(\dot{V}_I \times FIO_2\right) - \left(\dot{V}_E \times FEO_2\right)$$

Where FIO_2 is the fraction of O_2 in inspired air, FEO_2 is the fraction of O_2 in expired air. $\dot{V}_I$ is the volume of inspired air and is described in Equation 5 and $\dot{V}_E$ is the volume of expired air and is described in Equation 6.

Equation 5

$$\dot{V}_I = \dot{V}_E \times \frac{1 - (FEO_2 + FECO_2)}{1 - (FIO_2 + FICO_2)}$$

Volume of inspired air ($\dot{V}_I$) where FEO_2 is the fraction of O_2 in expired air, $FECO_2$ is the fraction of CO_2 in expired air, FIO_2 is the fraction of O_2 in inspired air and $FICO_2$ is the fraction of CO_2 in inspired air. $\dot{V}_E$ is described in Equation 6.

Volume of expired air (standard temperature, pressure and dry) $\dot{V}_E(STPD)$:

Equation 6

$$\dot{V}_E(STPD) = \dot{V}_E(ATPS) \times \frac{(273)}{(273 + T)} \times \frac{(P_B - PH_2O)}{760}$$

Volume of expired air ($\dot{V}_E$) at standard temperature, pressure and dry ($STPD$), where $\dot{V}_E$ at ambient temperature, pressure and saturated with water vapour ($ATPS$) is described in Equation 7, T is temperature of sample gas in volume measuring device (°C), P_B is barometric pressure (mmHg) and PH_2O is the partial pressure of water at T (mmHg).

Equation 7

$$\dot{V}_E(ATPS) = \left(\frac{V}{t}\right) \times 60$$

$\dot{V}_E$ at ambient temperature, pressure and saturated with water vapour ($ATPS$), where V is volume (L) and t is duration of the sample (s).

Volume of carbon dioxide ($\dot{V}CO_2$):

Equation 8

$$\dot{V}CO_2 = \left(\dot{V}_I \times FICO_2\right) - \left(\dot{V}_E \times FECO_2\right)$$

Where $FICO_2$ is the fraction of CO_2 in inspired air, $FECO_2$ is the fraction of CO_2 in expired air. $\dot{V}_I$ is described in Equation 5 and $\dot{V}_E$ is described in Equation 6.

Respiratory exchange ratio (RER):

Equation 9

$$RER = \frac{\dot{V}CO_2}{\dot{V}O_2}$$

Where $\dot{V}CO_2$ is the volume of CO_2 and $\dot{V}O_2$ is the volume of O_2.

Resting measurements were obtained by collecting expirate for two min following supine lying for two min. Following the second and fourth SACM run on the centrifuge, expirate via tubing from the expirate valve of the RAF-type P/Q oronasal mask was collected for two min into two separate Douglas bags. Expirate automatically commenced collection for exactly 2 min once the centrifuge reached an idle speed of +1.5 Gz. The Douglas bags were located in a space above and behind the Mk 16 ejection seat in the centrifuge gondola (Figure 6.7).

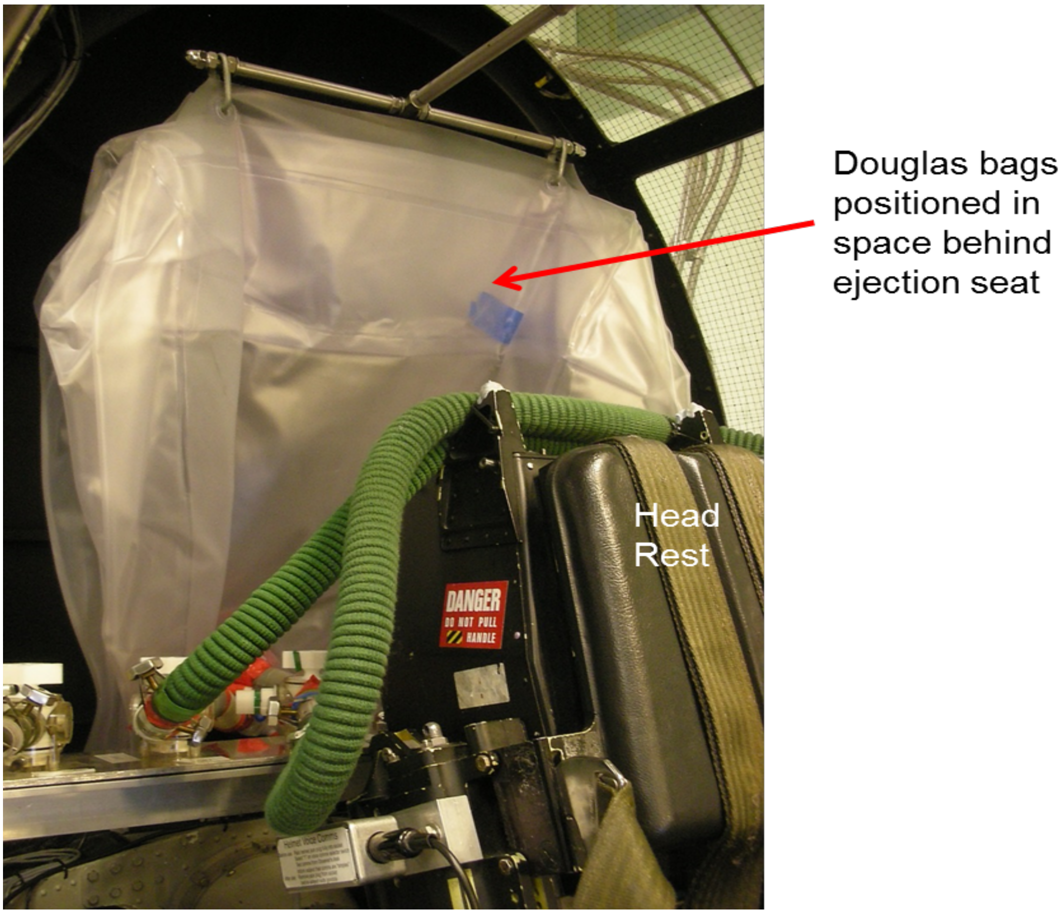

Figure 6.7 Two Douglas bags located in the space behind the Mk 16 ejection seat inside the centrifuge gondola.

Following completion of all the centrifuge runs, the Douglas bags were removed from the centrifuge gondola and the contents analysed. The contents of each Douglas bag was analysed over a 30 s period using a Servomax gas analyser (Servomax 1440D, Servomax, Crowbrough, UK) to calculate O_2 and CO_2. The gas volume was then calculated for each bag using a Havard Gas Meter (Dry Gas Meter 230V, Harvard Apparatus UK, Cambridge, UK).

6.2.4.4 *Blood Lactate*

Resting blood lactate was obtained following 4 min of supine lying via a finger prick blood sample collected from the lateral aspect of the first finger on the left hand using an Accu-Chek Softclix finger pricker (Accu-Chek, Roche Diabetes Care, West Sussex, UK). A small drop of blood was collected on a Lactate test strip (Lactate Pro™ Test Strips, Arkray, Kyoto, Japan) which was inserted into a hand-held lactate analyser (Lactate Pro™, Arkray, Kyoto, Japan). A second blood sample was obtained 180 s (Tamir et al, 1988) after the fourth SACM.

6.2.4.5 *EMG*

EMG was recorded from the vastus lateralis (VL), biceps femoris (BF) and the gastrocnemius lateralis (GL) on the left leg throughout the centrifuge runs. The left leg was chosen as it provided the optimum EMG signal when participants were sitting in the gondola. Prior to electrode placement the surface of the skin was shaved, lightly abraded and cleaned with alcohol wipes. Electrode placements (Table 6.1) were in accordance with the European recommendations for surface EMG (Hermens, et al., 1999). Electrodes were attached to the subject with the use of Ambu BluSensor pads (Ambu® BluSensor N, Ambu, St Ives, UK) via snap leads. The electrodes were applied with a 20 mm separation between them for optimal signal detection. All hanging cables were secured to the subject with medical tape (Kinesio Tape®, Kinesiotaping, Japan). Medical tape was also used over the electrodes to ensure they remained in place during the centrifuge runs. All electrodes were placed on the left side of the body (Figure 6.8).

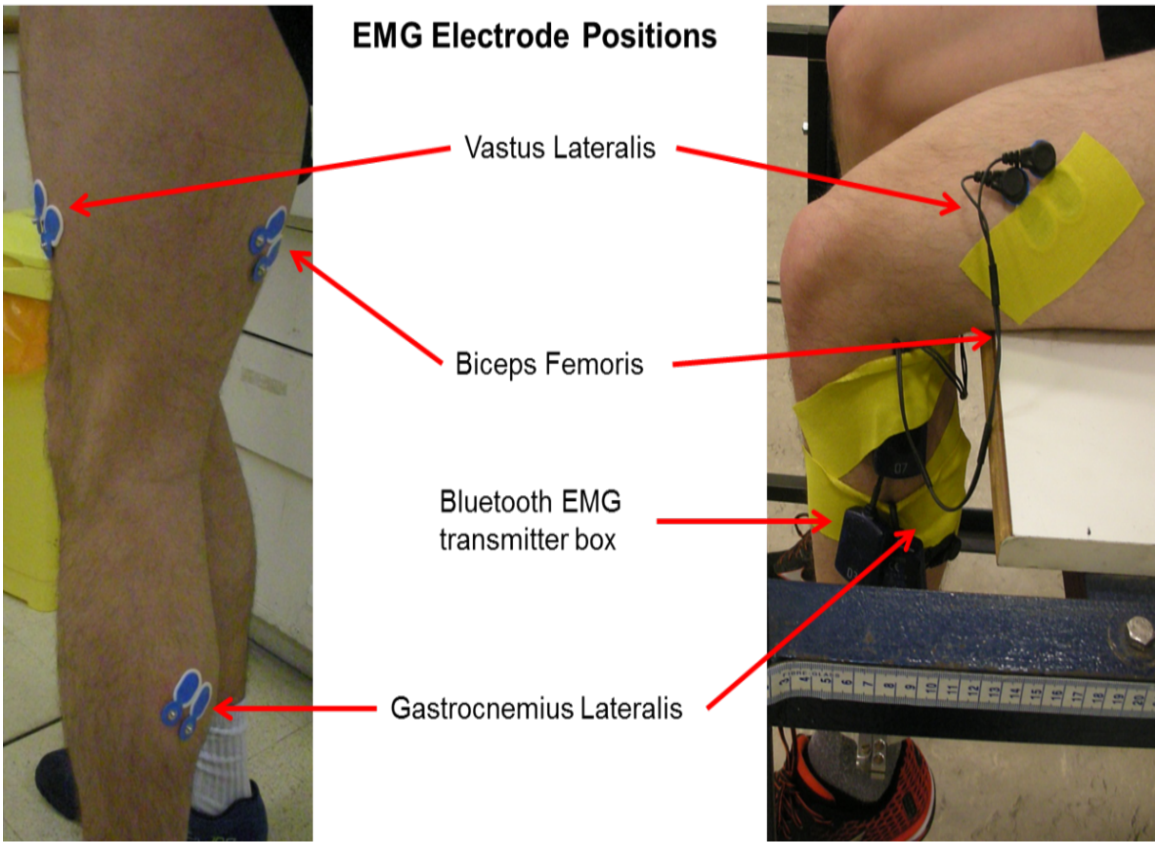

Figure 6.8 EMG electrode positions used during MVCs and centrifuge runs.

The subjects were asked to perform a series of isometric maximum voluntary contractions (MVC) targeting the muscles described in Table 6.1 to enable normalisation of electromyography data acquired under sustained +Gz.

Muscle	Electrode Placement
Vastus Lateralis (VL)	2/3 of the way along a line from the anterior superior iliac spine and the superior lateral aspect of the patella
Biceps Femoris (BF)	half way along a line from the ischial tuberosity and the lateral epicondyle of the tibia
Gastrocnemius Lateralis (GL)	1/3 of the way along a line from the head of the fibula to the superior aspect of the heel

Table 6.1 EMG electrode positions with reference to various anatomical landmarks

EMG data was recorded on an 8-channel system (m320, Myon AG, Switzerland) with the use of wireless Myon Radio Frequency Transmitting Devices (RFTD) electrodes. EMG was sampled at a frequency of 2000 Hz (PowerLab 16/SP, AD Instruments, Oxford, UK) and stored on a computer for offline analysis. The EMG signal was recorded with a gain of 1000x using an inbuilt filter within the unit which is a 4^{th} order band-pass filter between frequencies of 5 to 500 Hz (Myon m320, Myon AG, Switzerland). Analysis of all EMG data was performed with LabChart version 7 (LabChart Pro v7, AD Instruments, Oxford, UK).

6.2.4.6 *Knee Flexion/Extension*

Isometric MVCs of the left knee flexors and extensors were performed with the subjects sitting in a bespoke rig with the hip and knee joints at 90° of flexion. To minimise movement and contribution of other muscles, the subjects were strapped to the rig using a belt around the hips plus two belts criss-crossing the chest and shoulders. Their arms were kept crossed and over the chest. A total of three isometric MVCs of each muscle group were performed with standardised verbal encouragement for 5 s with 30 s rest between each contraction. The greatest force from the 3 isometric MVCs was determined. Isometric MVCs were obtained for knee extensors (knee extensor torque) (Figure 6.9) by pushing against a fixed lever arm placed 0.03 m proximal to the ankle. Isometric MVCs for knee flexors (knee flexor torque) by pulling against a fixed lever arm (Figure 6.10). The force was digitised (Tedea Huntleigh 615 Load Cell (200 kg), Vishay Measurement Group, Basingstoke, UK) and stored on a computer for subsequent offline analysis.

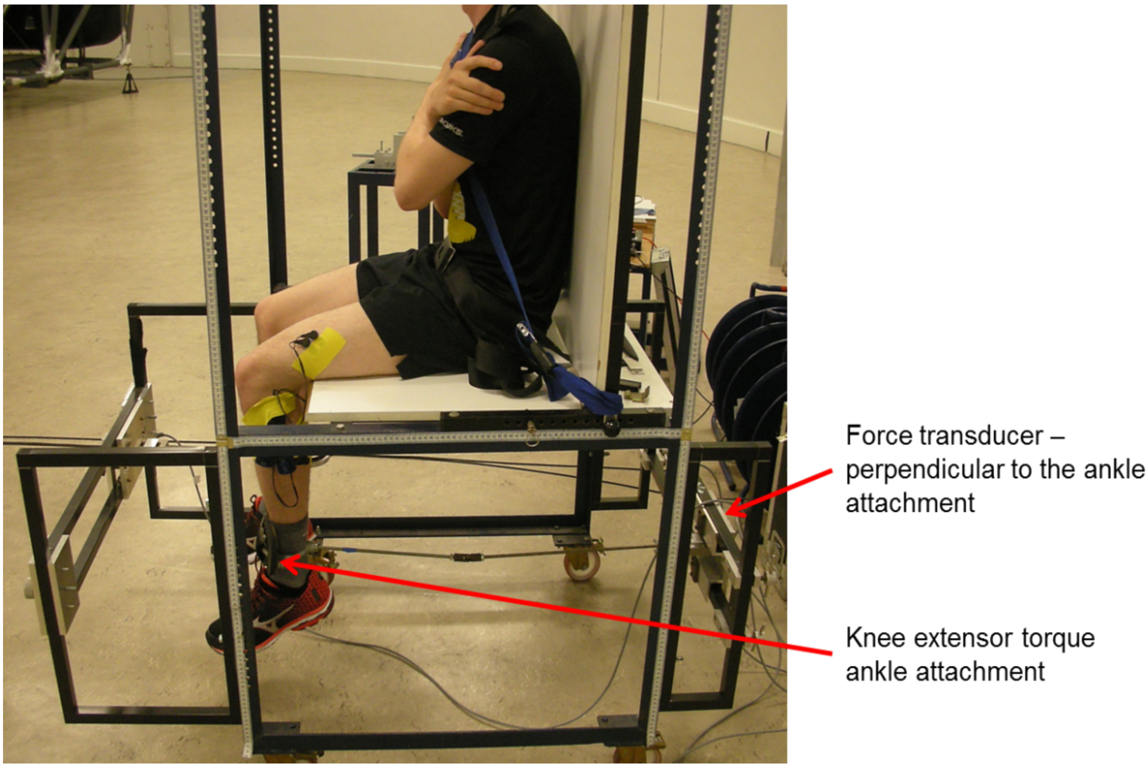

Figure 6.9 Rig used to perform maximum voluntary contractions of the leg muscles, configured to measure knee extensor torque.

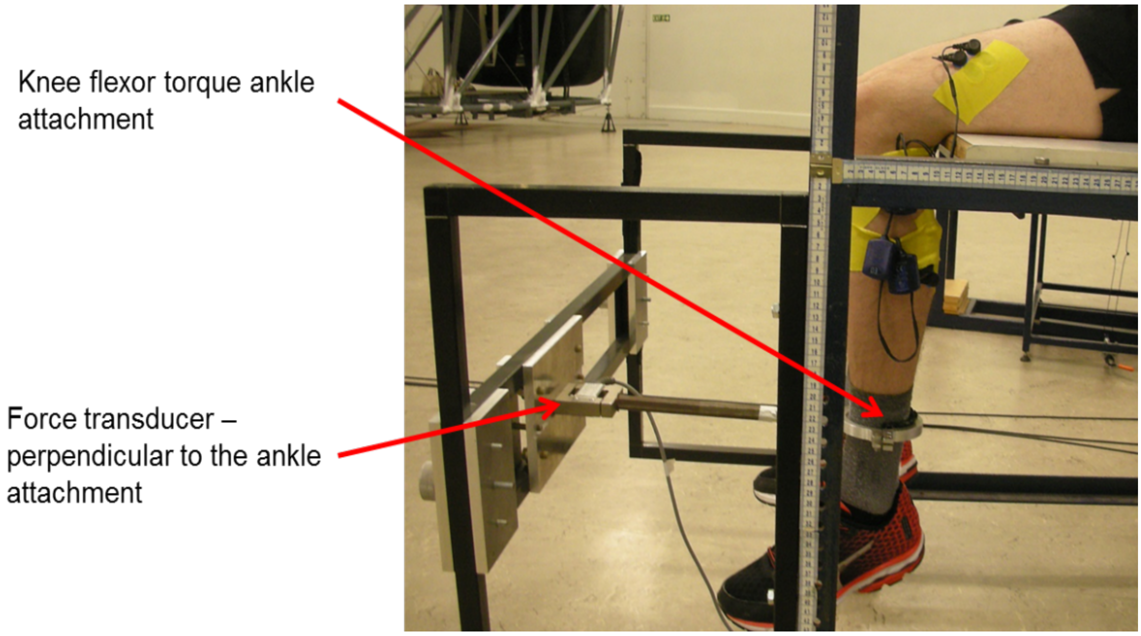

Figure 6.10 Rig used to perform MVCs of the leg muscles, configured to measure knee flexor force.

6.2.4.7 *Ankle Plantar Flexion*

MVCs for ankle plantar flexors on the left leg were obtained with the subject sitting in a bespoke rig with the foot flat on an adjustable platform and the ankle at 90° (Figure 6.11). Subjects were positioned with the knee and hip at 90° of flexion, with the knee held in place by the rig which minimised movement. To minimise additional movement and contribution of other muscles, the subjects were told to keep their arms crossed across their chest. The force transducer was positioned directly above the ankle joint and plantar flexion strength was assessed by trying to raise the heel of the foot. The MVC test protocol described earlier was used.

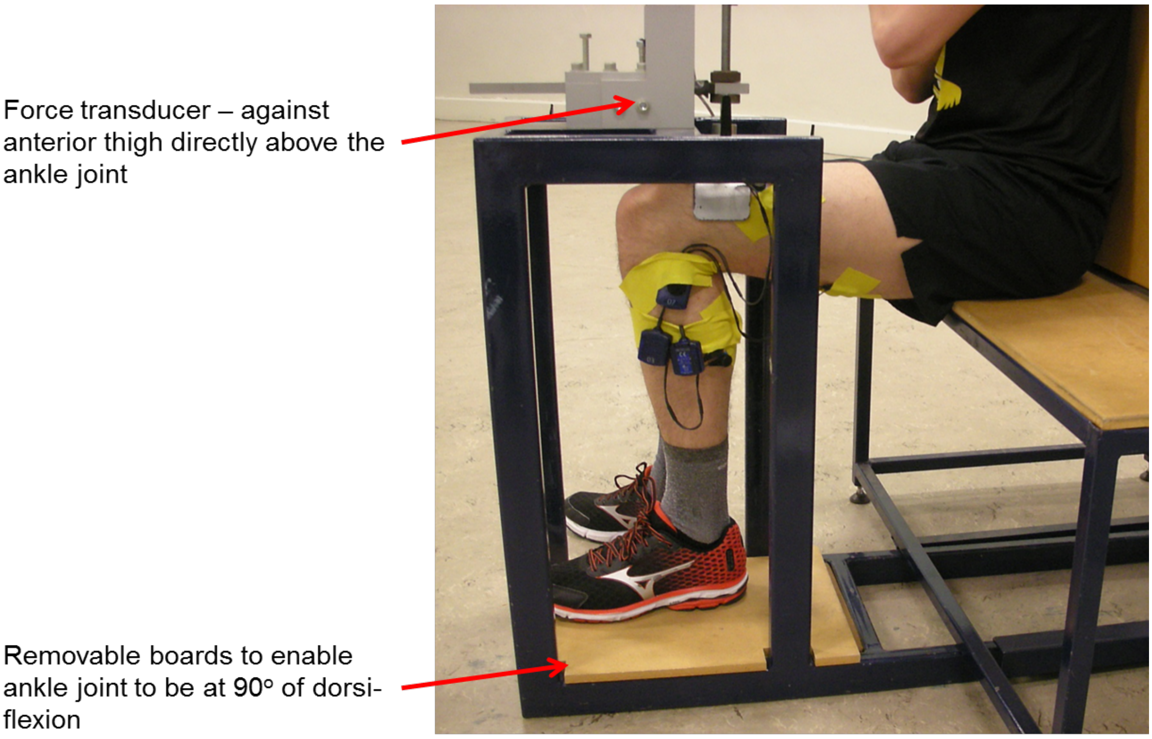

Figure 6.11 Rig used to perform MVCs of the ankle plantar flexor muscles.

6.2.4.8 *Foot Pedal Force*

Foot pedal force exerted during centrifuge exposures has been suggested as a method of assessing physical exertion during +Gz exposures. Contraction of the leg muscles combined with pressure on the foot pedals may be important in +Gz tolerance (Eliasz, 2004). Following completion of SACM exposures to voluntary exhaustion, subjects were still able to generate the same maximal leg muscle forces as they were prior to the SACM exposures (Bain et al. 1995). Sub-maximal fatigue of the leg muscles may be a limiting factor to +Gz performance hence measurement of time to maintain 30% of maximal force was recorded.

Subjects were asked to generate a maximum foot pedal force (utilising all the muscles of the legs) by pushing against the foot pedals located in the centrifuge gondola (Figure 6.12) for a 5 s period. After a 5 min rest period, subjects then pushed against the foot pedals to maintain 30% of the force recorded during the maximum contraction by reference to a monitor displaying the output from a load cell. Subjects were asked to sustain this pressure for as long as possible, terminating when they could not maintain this level any longer. Standardised verbal encouragement was provided. To minimise movement and contribution of other muscles, the subjects were strapped to the ejection seat via a 4-point harness which held the shoulders and hips in place and arms were kept crossed over the chest (Figure 6.13).

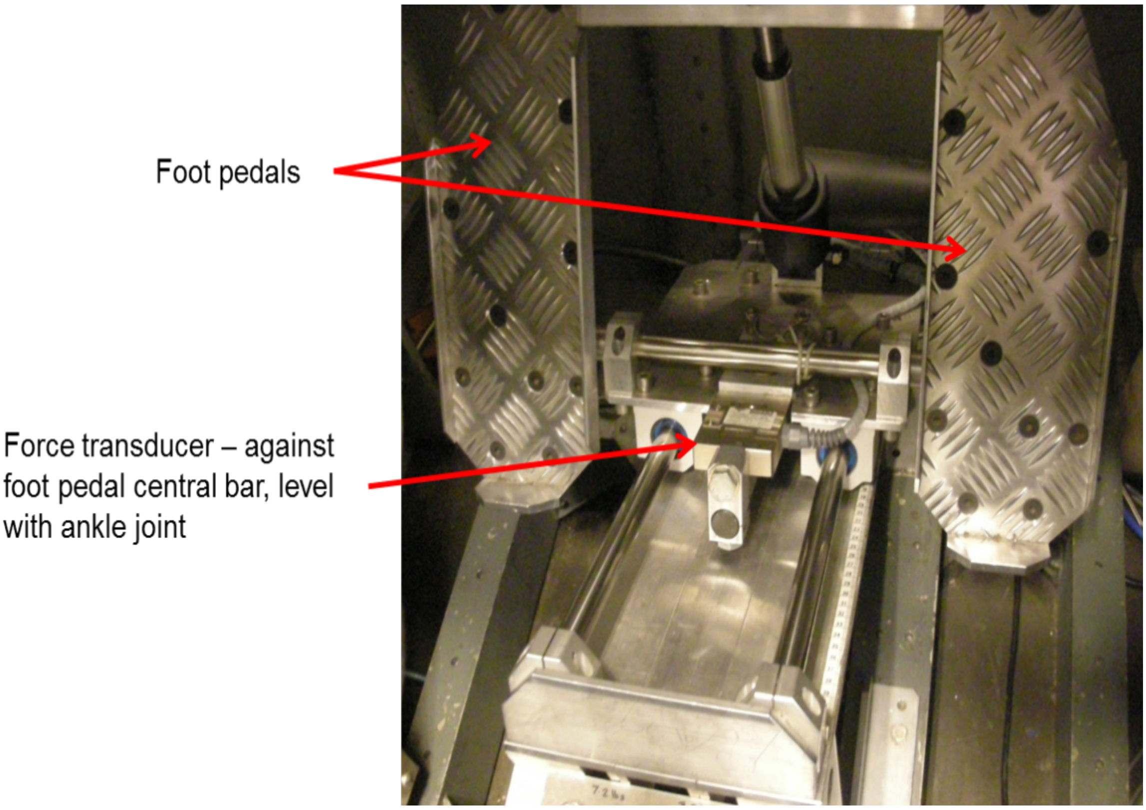

Figure 6.12 Load cell location between the foot pedals in the centrifuge gondola.

Figure 6.13 Subject position during maximum and 30% of maximum leg push, seated in the centrifuge gondola.

After a minimum period of 60 min rest to allow sufficient recovery, the acceleration exposures described earlier commenced. Foot pedal force was recorded throughout the centrifuge exposures.

Following a 5 min rest after completion of all the centrifuge runs, subjects repeated the procedure to maintain 30% of the maximum leg push force. They were asked to sustain this pressure for as long as possible, terminating when they could not maintain this level any longer. The time to failure pre- and post- centrifuge runs was recorded.

6.2.5 Centrifuge Measurements

A number of additional measurements were recorded during the centrifuge exposures.

6.2.5.1 *Rating of Perceived Exertion*

The subjects were asked to provide a Rating of Perceived Exertion (RPE) after each SACM on the centrifuge. This was achieved using the BORG category-ratio scale (CR-10) (Borg et al. 1985) which is modified from BORG RPE-scale (Borg 1982). A strong relationship has been reported between this and exercise intensity, assessed by blood lactate and heart rate (Scherr et al. 2013). The CR-10 was used to provide a simple measure of RPE with the subjects.

6.2.5.2 *Visual Light Loss Under +Gz*

A modified 'light bar' technique was used with three lights presented to subjects at eye level, comprising a central, continuous white light and a flashing (1 Hz) red light to either side (each placed at an angle of 30° from the center of the subjects vision). Subjects fixated on central white light and depressed the 'stop' button when the red lights were no longer perceived (60° peripheral visual loss). This initiated centrifuge deceleration and provided a step voltage change to the data acquisition system. The +Gz level measured at the moment of this voltage change was taken as the +Gz for that run (Scott et al. 2013).

6.2.6 Training Intervention

Following completion of all centrifuge measurements the groups were separated into their predetermined intervention groups (Figure 6.14). The ACP group participated in the 12-week ACP (Table 5.1) delivered twice a week (with a rest day between sessions) by trained PTIs and physiotherapist during the ground-school and flying stage of BFJT at RAF Linton-on-Ouse. The ACP has been shown to have construct validity and is described in greater detail in Chapter 5.

The Control group were advised to continue with their current established exercise regimen (with no specific anaerobic/strength training or cervical spine strengthening). Subjects in both groups were instructed to complete a weekly activity log (Appendix 6) described in greater detail in section 6.2.1. After a period of 12 weeks, both groups were reassessed.

6.2.7 Data Acquisition

Analogue-to-digital conversion of all measured physiological parameters was performed using a PC based data acquisition system sampled at a frequency of 2000 Hz (Powerlab 16/s data acquisition system, AD Instruments, Oxford, UK) using LabChart version 7 (LabChart Pro v7, AD Instruments, Oxford, UK).

6.2.8 Statistical Analysis

All data analysis was performed using SPSS v24 (v 24.0.0.0, IBM SPSS Inc, Chicago, IL). Normality of the data was assessed using Kolmogorov-Smirnov, with p = .05. An independent samples t-test was used to compare the control and exercise group baseline measurements. A 2x2 mixed ANOVA with time within and group between with

Bonferroni post-hoc analysis was used for parametric data. Kruskall-Wallis was used for non-parametric data.

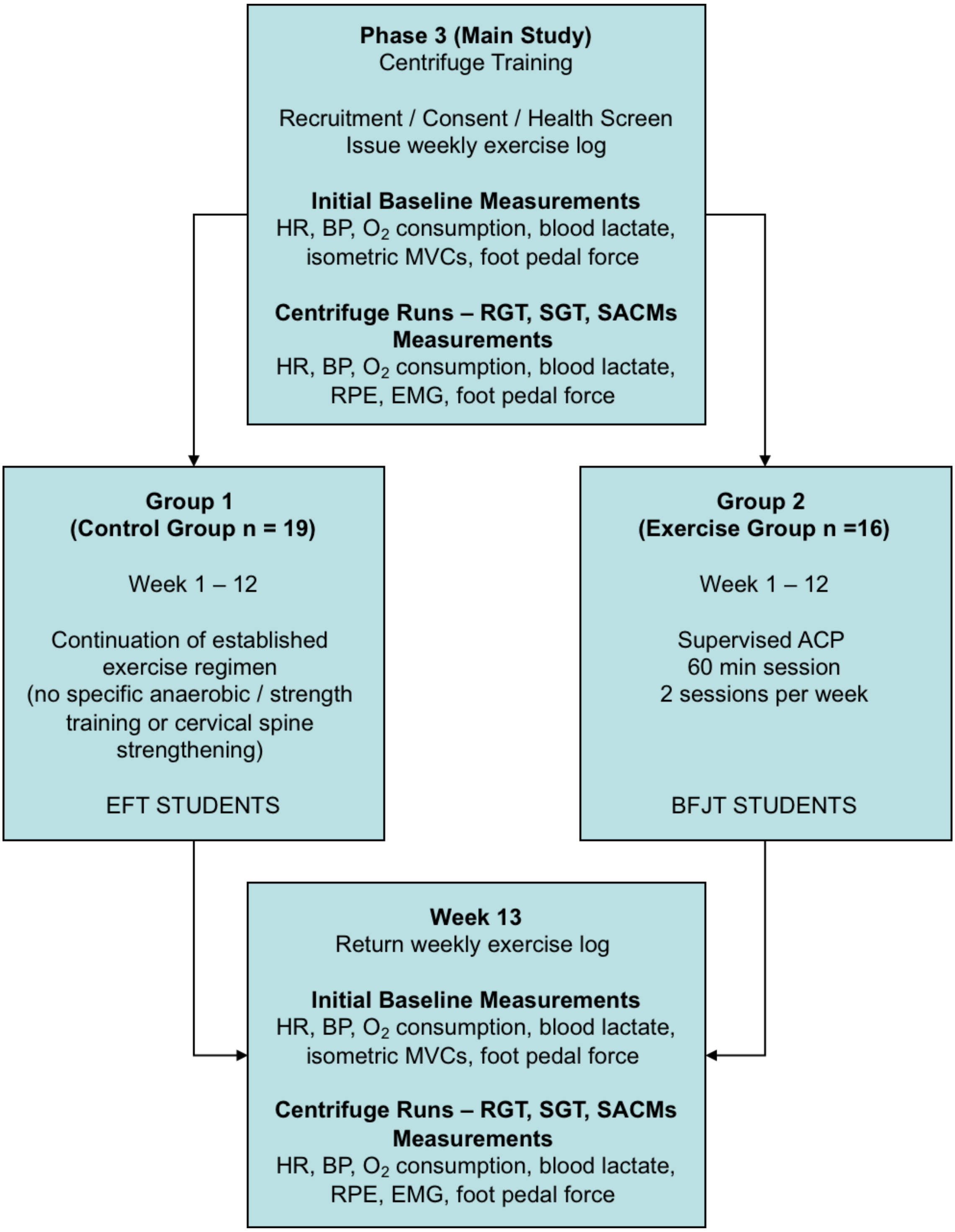

Figure 6.14 Flow diagram of study to determine whether the ACP would have a beneficial effect on aircrew performance in a controlled high +Gz environment.

6.3 Results

Thirty-six subjects participated in the study. The results will be presented as subject characteristics then subject performance during the centrifuge runs (RGT, SGT and SACM) and are summarised below in Table 6.2.

	Control Group (n = 19)		ACP Group (n = 16)		
	Pre	Post	Pre	Post	*p* value
RGT Level (+Gz)	4.6 ± 0.2	4.5 ± 0.2	4.2 ± 0.2	4.4 ± 0.2	*.06*
HR Response (beats.min^{-1})	7.5 ± 0.6	7.5 ± 1.0	7.8 ± 0.9	6.6 ± 1.0	*NS*
SGT Level (+Gz)					
HR at +5.5 Gz Step (beats.min^{-1})	148.0 ± 0.0	153.1 ± 3.3	146.0 ± 4.4	↓ 136.9 ± 5.6	.004*
MAP at +5.5 Gz Step (mmHg)	157.8 ± 5.2	154.0 ± 5.7	166.9 ± 5.7	155.7 ± 6.2	
SBP at +5.5 Gz Step (mmHg)	220.6 ± 8.3	↓197.6 ± 7.9	215.1 ± 9.1	224.0 ± 8.7	.007*
DBP at +5.5 Gz Step (mmHg)	133.9 ± 4.5	124.0 ± 4.9	133.9 ± 4.9	131.4 ± 5.4	
SACMs					
Number of +7 Gz Peaks Completed	14.0 ± 1.0	13.6 ± 1.1	13.9 ± 1.2	15.4 ± 0.4	*NS*
Maximum Foot Pedal Force (Nm)	3731 ± 296	4233 ± 285	4187 ± 322	↑ 4800 ± 311	.002*

Table 6.2 Summary of results for Relaxed +Gz Tolerance (RGT), Straining +Gz Tolerance (SGT), Simulated Air Combat Manoeuvre (SACM) centrifuge runs and initial testing. Values are mean ± SE. *There was a significant difference between the groups.

All subjects in the Control group returned for re-testing, but one from the ACP group was unable to complete re-testing on the centrifuge due to a recent ankle injury. Repeat baseline testing was possible with this participant and is included in subsequent analysis (Table 6.3); however the participant's MVC and centrifuge data from pre-intervention have been excluded (Table 6.4).

6.3.1 *Subject Characteristics*

There was a significant difference between the groups for age and resting HR (Table 6.3) at baseline. The ACP group were significantly older (25.8 ± 0.5 years) than the Control group (23.4 ± 0.4 years); $t(34) = -3.661$, $p = .001$. The ACP group also had a significantly lower resting HR (56.4 ± 2.3 beats.min^{-1}) than the Control group (65.3 ± 1.8 beats.min^{-1}); $t(34) = 3.070$, $p = .004$. There was no other significant difference between the groups for any other baseline measurements and (Table 6.4).

	Control (n = 19)	**ACP (n = 17)**
Age (years)	23.4 ± 0.4	25.8 ± 0.5*
Height (m)	1.80 ± 0.01	1.81 ± 0.01
Mass (kg)	82.9 ± 2.1	81.0 ± 2.2
BMI	25.7 ± 0.5	24.8 ± 0.6
Resting Heart Rate (beats.min^{-1})	65.3 ± 1.8	56.4 ± 2.3*
Systolic Blood Pressure (mmHg)	122.2 ± 2.7	118.3 ± 2.3
Diastolic Blood Pressure (mmHg)	67.3 ± 1.3	64.4 ± 1.7
Mean Arterial Pressure (mmHg)	85.6 ± 1.7	82.4 ± 1.5
Blood Lactate (mmol.L^{-1})	1.8 ± 0.1	2.3 ± 0.2

Table 6.3 Initial measurements for both groups. Values are mean ± SE. *The ACP group were significantly older ($p < .001$) and had a significantly lower resting heart rate ($p < .004$) compared to the Control group. There were no other significant differences between the groups for any of the measurements.

	Control (n = 19)	ACP (n = 16)
Knee Extensor Torque (Nm)	205.7 ± 13.3	210.7 ± 11.3
Knee Flexor Torque (Nm)	83.2 ± 7.5	91.7 ± 7.3
Calf Strength (N)	1468.4 ± 85.2	1374.3 ± 79.0
Foot Plate Force (N)	3730 ± 333	4187 ± 264

Table 6.4 Initial measurements for both groups with adjusted data for excluded subject in ACP group. Values are mean ± SE. There were no significant differences between the groups for any of the measurements.

6.3.1.1 *Weekly Activity Log*

Self-reported physical activity levels were similar in both groups apart from participation in the intervention by the ACP group. They completed more flight hours (33.02 ± 3.6 hours) than the Control group (8.83 ± 1.19 hours), but neither group participated in any NVG or ACM/BFM flying.

6.3.2 *Relaxed +Gz Tolerance*

There was no significant difference between the groups for baseline mean RGT; ACP group (4.24 ± 0.19 Gz); Control group (4.60 ± 0.14 Gz); $t(33) = 1.533$, $p = .135$. There was no significant reduction in mean RGT in the ACP group as result of the training programme. There was no effect of Group, $F(1,33) = 1.179$, $MSE = 1.013$, $p = .285$, or Time, $F(1,33) = 0.01$, $MSE = 0.001$, $p = .921$, but there was a tendency for an interaction of these two factors, $F(1,33) = 3.778$, $MSE = 0.239$, $p = .060$, with RGT for the ACP group increasing by +0.12 Gz and the Control group RGT decreasing by +0.11 Gz (Figure 6.15).

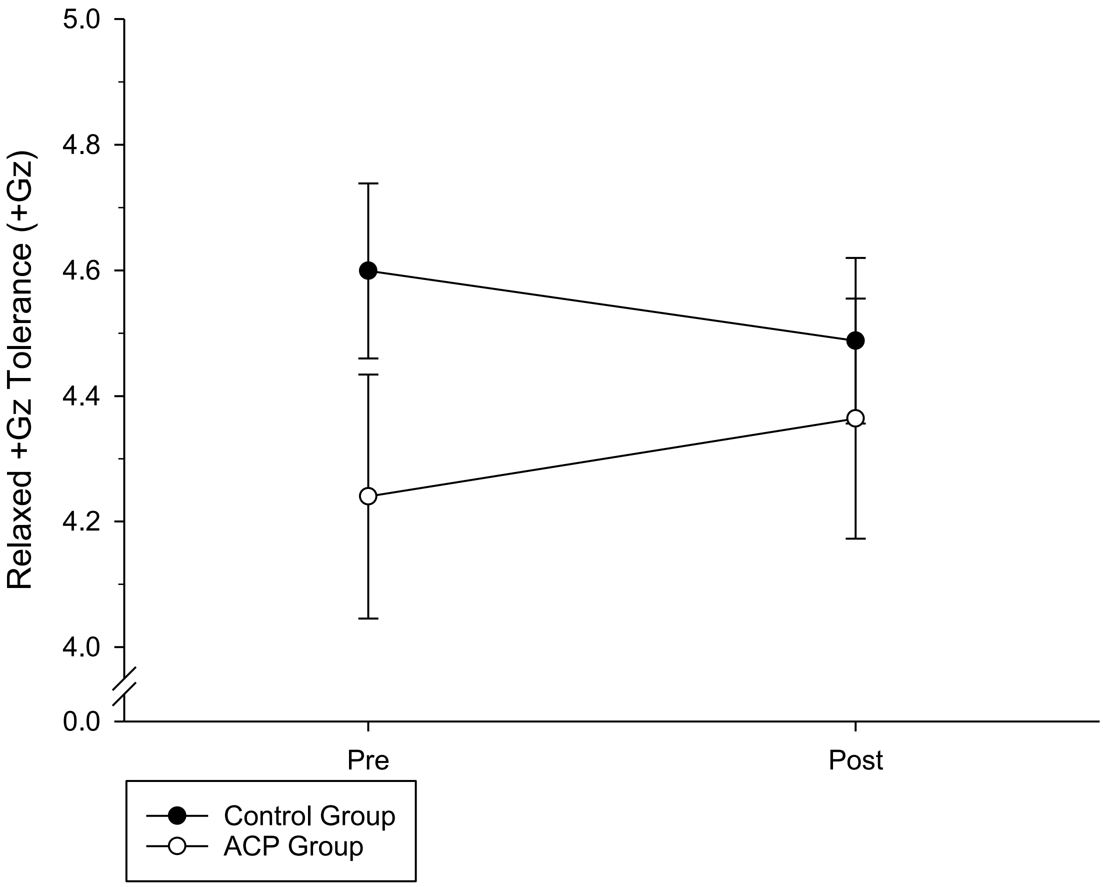

Figure 6.15 RGT for the Control (n = 19) and ACP (n = 16) group pre (Control 4.60 ± 0.16, ACP 4.24 ± 0.17) and post (Control 4.49 ± 0.15, ACP 4.36 ± 0.17) intervention. Values are group mean ± SE.

When comparing RGT for each run, there was no significant difference between each run at initial and re-testing, enabling the mean of the runs to be used.

6.3.2.1 *Heart Rate*

There was no significant change in HR response ($\Delta HR.G^{-1}$) during each RGT run for the ACP group (pre: 7.8 ± 0.9 beats.min^{-1}.G^{-1}, *vs* post: 6.6 ± 1.0 beats.min^{-1}.G^{-1}) and the Control group (pre: 7.5 ± 0.6 beats.min^{-1}.G^{-1}, *vs* post: 7.5 ± 1.0 beats.min^{-1}.G^{-1}). For the delta HR response ($\Delta HR.G^{-1}$) there was no effect of Group, $F(1,33) = 0.046$, $MSE = 0.894$, $p = .831$, Time, $F(1,33) = 1.002$, $MSE = 7.900$, $p = .324$, or interaction of these two factors, $F(1,33) = 1.071$, $MSE = 8.452$, $p = .308$.

6.3.3 Straining +Gz Tolerance

SGT was not normally distributed and was unchanged in both the ACP group (pre: 6.39 ± 0.13 Gz, *vs* post: 6.46 ± 0.18 Gz) and the Control group (pre: 6.79 ± 0.06 Gz, *vs* post: 6.71 ± 0.10 Gz) p = .541 (Figure 6.16). There was a significant difference between the groups for baseline SGT; t(21.572) = 2.741, p = .012.

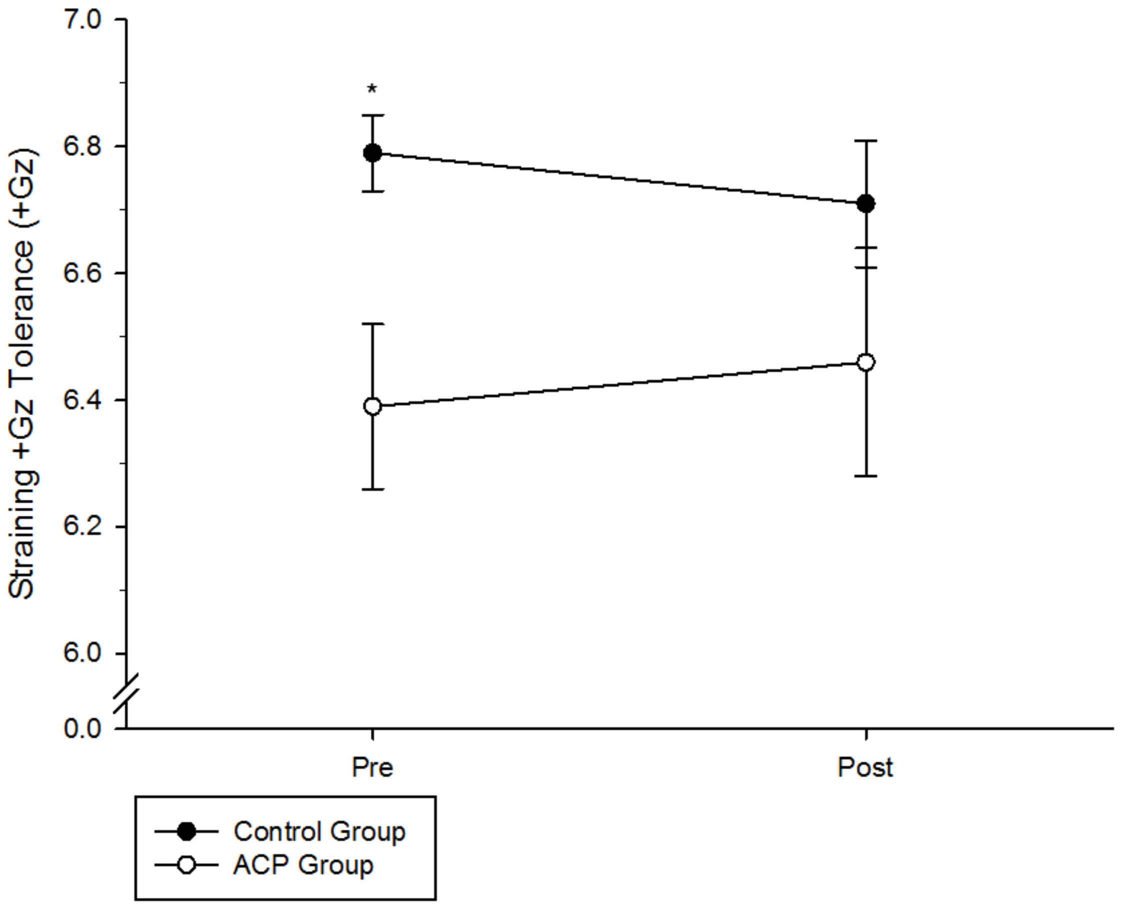

Figure 6.16 SGT for the Control (n = 19) and ACP (n = 16) group pre (Control 6.79 ± 0.06, ACP 6.39 ± 0.13) and post (Control 6.71 ± 0.10, ACP 6.46 ± 0.18) intervention. Values are group mean ± SE. *Significant difference between the groups for baseline best SGT run (p = .012).

The point at which subjects initiated tensing of the lower limb muscles during the stepped profile varied considerably (Figure 6.17), however all had commenced some form of strain by the +5.5 Gz plateau and this is the reason why it was used for subsequent analysis. Unfortunately, one subject in the ACP group was unable to reach the +5.5 Gz plateau on both pre and post intervention SGT runs and their data has been excluded from further +5.5 Gz analyses.

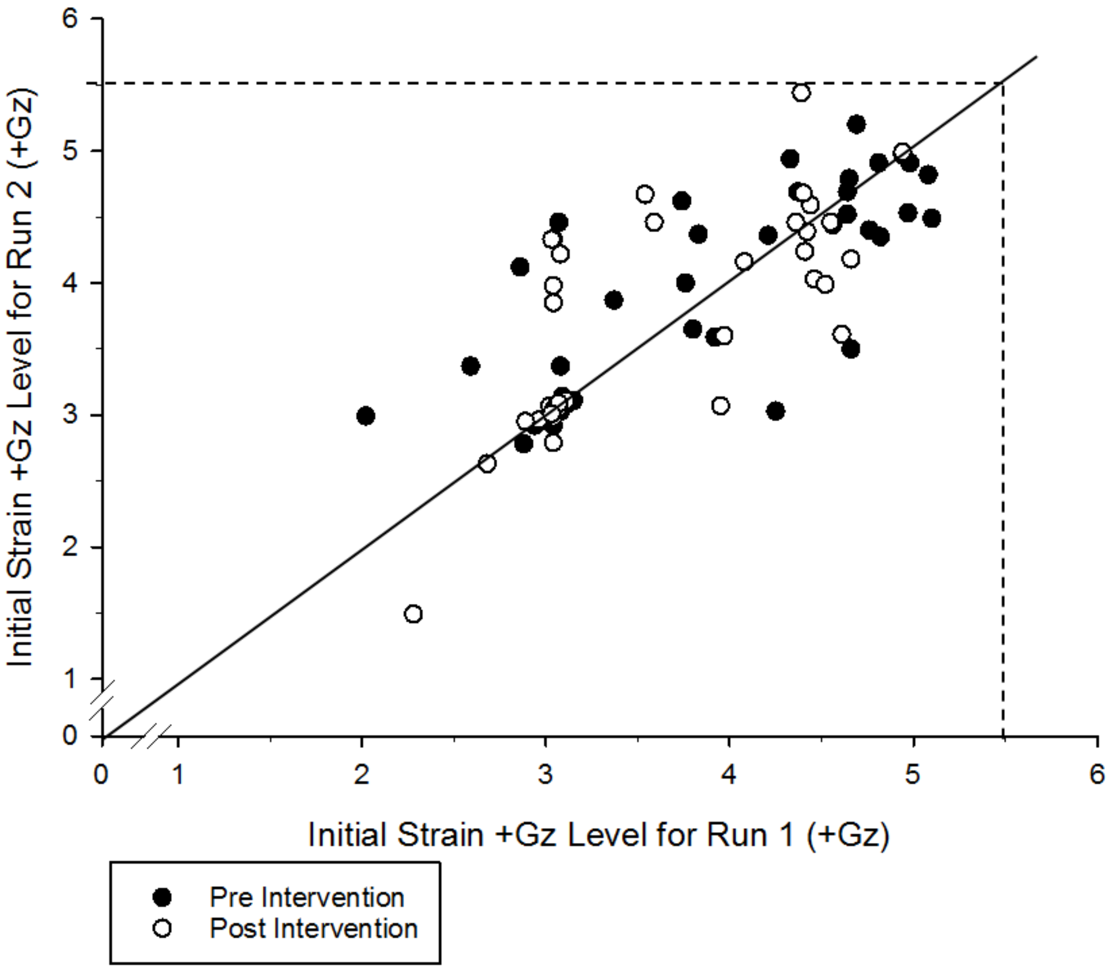

Figure 6.17 Initial strain +Gz level for all subjects during SGT runs pre and post intervention. The dashed line indicates the +5.5 Gz plateau which was then used for subsequent analysis. The bold diagonal line is a line of identity.

There was a significant difference between the groups for the baseline initial strain +Gz level on run 1; ACP group (3.61 ± 0.23 Gz); Control group (4.23 ± 0.16 Gz); $t(34) = 2.279$, $p = .029$.

6.3.3.1 *Heart Rate*

HR was averaged over the last two seconds of each plateau in order to capture the greatest effect of +Gz. During the +5.5 Gz plateau the ACP group only demonstrated a reduction in HR for the equivalent load (pre: 146.0 ± 4.4, *vs* post: 137.0 ± 5.6 beats.min^{-1}); Control group (pre: 148.0 ± 3.2, *vs* post: 153.1 ± 3.3 beats.min^{-1}). There was no effect of Group, $F(1,32) = 2.743$, $MSE = 1436.03$, $p = .107$, or Time, $F(1,32) = 1.009$, $MSE = 62.28$, $p = .323$, but there was a significant interaction of these two factors, $F(1,32) = 13.35$, $MSE = 823.96$, $p = .001$. Post-hoc tests showed that the ACP group significantly reduced by 10 beats.min^{-1} ($p = .004$) (Figure 6.18).

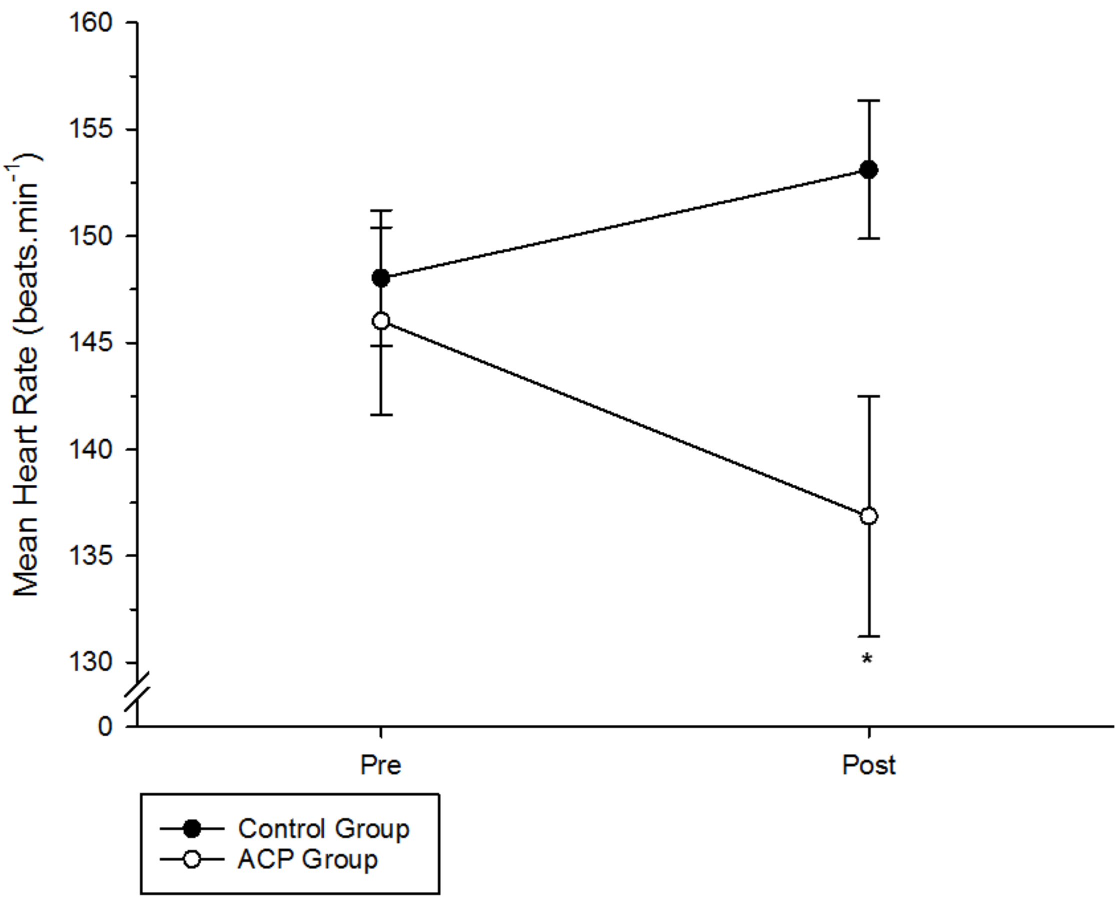

Figure 6.18 Mean HR during the last two seconds of the SGT +5.5 Gz plateau for the Control (n = 19) and ACP (n = 15) group pre and post intervention. Values are group mean ± SE. *Significant difference between groups (*p* = .004).

SGT Heart Rate Sub Group Analysis

A total of 6 subjects from the ACP group and 11 from the Control group reached the +7 Gz plateau on both pre and post intervention SGT. HR from these subjects is shown in Figure 6.19. The 6 subjects from the ACP sub-group had a lower, but not statistically lower, mean HR (pre: 161.6 ± 9.3, *vs* post: 153.5 ± 6.3 beats.min^{-1}) compared with the 11 subjects in Control sub-group (pre: 176.4 ± 4.7, *vs* post: 175.7 ± 3.7 beats.min^{-1}). There was a significant effect of Group, $F(1,15) = 5.97$, $MSE = 2655.03$, $p = .027$, no effect of Time, $F(1,15) = 2.26$, $MSE = 149.87$, $p = .154$, and the interaction of these two factors was not significant, $F(1,15) = 1.589$, $MSE = 105.34$, $p = .227$. Post-hoc tests were not significant. It is noted that a significant difference existed between the groups for baseline HR; Control group (65.3 ± 1.8 beats.min^{-1}) and ACP group (56.4 ± 2.3 beats.min^{-1}); $t(34) = 3.070$, $p = .004$.

On the +5.5 Gz plateau the ACP sub-group had a significant reduction in HR (pre: 136.5 ± 9.1, *vs* post: 125.5 ± 10.8 beats.min^{-1}) compared with the Control sub-group (pre: 148.8 ± 4.6, *vs* post: 154.8 ± 4.1 beats.min^{-1}). There was a significant effect of Group, $F(1,15) = 4.932$, $MSE = 2943.45$, $p = .042$, no effect of Time, $F(1,15) = 1.532$, $MSE = 117.25$, $p = .235$, and there was a significant interaction of these two factors, $F(1,15) = 5.237$, $MSE = 400.75$, $p = .037$. Post-hoc tests showed that the ACP group significantly reduced by 11 beats.min^{-1} ($p = .045$) (Figure 6.19).

There was no change in the ACP sub-group HR during the +3.0 Gz plateau (pre: 107.6 ± 7.4, *vs* post: 104.2 ± 8.4 beats.min^{-1}) compared with the Control sub-group (pre: 125.0 ± 2.2, *vs* post: 123.3 ± 3.4 beats.min^{-1}). There was a significant effect of Group, $F(1,15) = 9.045$, $MSE = 2587.83$, $p = .009$, no effect of Time, $F(1,15) = 0.65$, $MSE = 53.16$, $p = .433$, and no significant interaction of these two factors, $F(1,15) = 0.073$, $MSE = 5.99$, $p = .790$ (Figure 6.19).

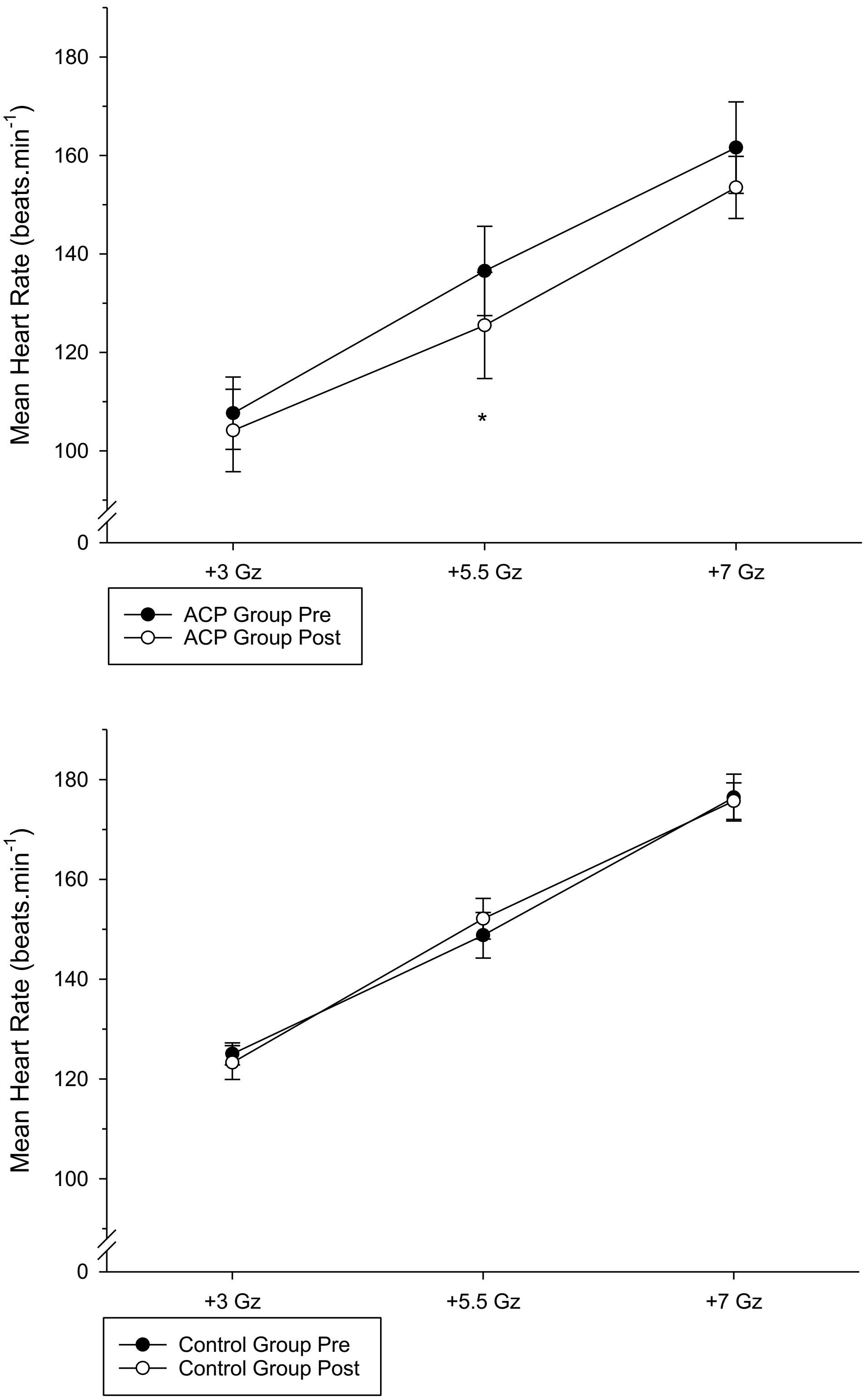

Figure 6.19 Mean HR for the ACP sub-group (n = 6) and Control sub-group (n = 11) who reached the +7 Gz plateau on both initial (pre intervention) and re-testing of SGT (post intervention). HR during the last two seconds of the SGT +3 Gz, +5.5 and +7 Gz plateau for each sub-group is shown. Values are sub-group mean ± SE. *The ACP group had a significantly lower HR at the +5.5 Gz plateau (p = .045).

6.3.3.2 *Blood Pressure*

BP was also averaged over the last two seconds of each plateau in order to capture the greatest effect of +Gz. Mean arterial pressure (MAP) for the ACP group was unchanged during the +5.5 Gz plateau (pre: 166.9 ± 5.7, *vs* post: 155.7 ± 6.2 mmHg, Control group pre: 157.8 ± 5.2, *vs* post: 154.0 ± 5.7 mmHg) when comparisons were made within each group and also between the two groups pre and post intervention (Figure 6.20). There was no effect of Group, $F(1,31) = 0.598$, $MSE = 479.74$, $p = .445$, Time, $F(1,31) = 3.427$, $MSE = 923.40$, $p = .074$, or interaction of these two factors, $F(1,31) = 0.829$, $MSE = 223.45$, $p = .370$.

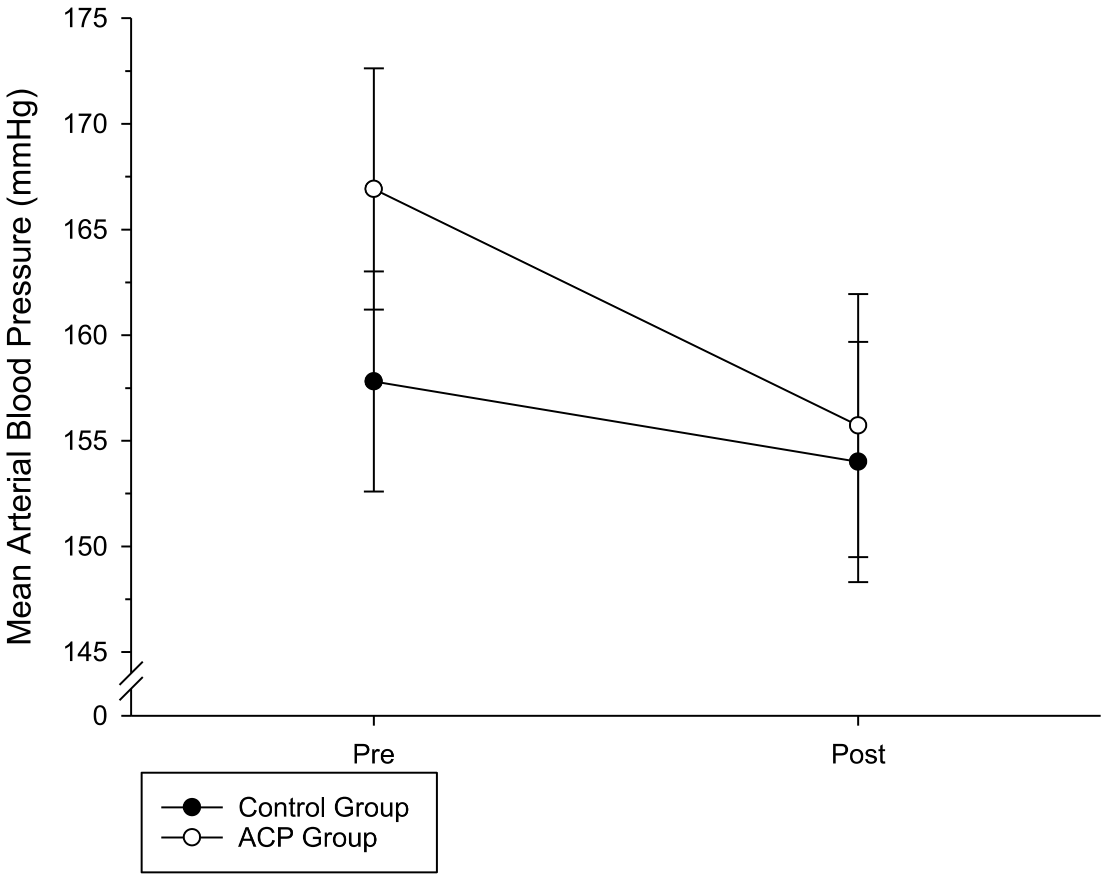

Figure 6.20 MAP during the last two seconds of the SGT +5.5Gz plateau for the Control (n = 18) and ACP (n = 15) group pre and post intervention. Values are group mean ± SE.

Systolic blood pressure (SBP) for the ACP group was unchanged during the +5.5 Gz plateau (pre: 215.1 ± 9.1, *vs* post: 224.0 ± 8.7 mmHg, Control group pre: 220.6 ± 8.3, *vs* post: 197.6 ± 7.9 mmHg) when comparisons were made within each group and also between the two groups pre and post-intervention (Figure 6.21). There was no effect of Group, $F(1,31) = 0.988$, $MSE = 1786.78$, $p = .328$, Time, $F(1,31) = 1.401$, $MSE = 809.82$, $p = .245$, but there was a significant interaction of these two factors, $F(1,31) = 7.183$, $MSE = 4150.87$, $p = .012$. Post-hoc tests showed that the Control group had a significantly lower SBP on re-test ($p = .007$).

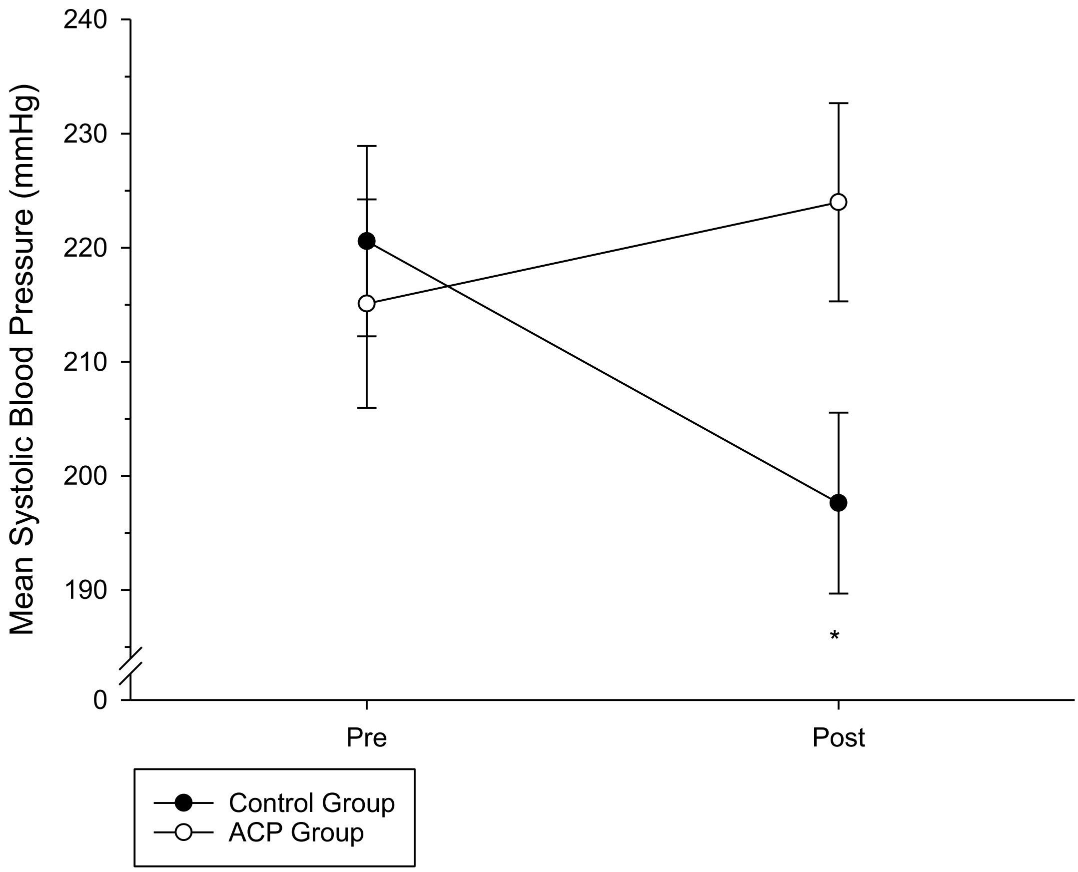

Figure 6.21 SBP during the last two seconds of the SGT +5.5Gz plateau for the Control (n = 18) and ACP (n = 15) group pre and post intervention. Values are group mean ± SE. *Control group had a significantly lower SBP on re-test ($p = .007$).

Diastolic blood pressure (DBP) for the ACP group was unchanged during the +5.5 Gz plateau (pre: 133.9 ± 4.9, *vs* post: 131.4 ± 5.4 mmHg, Control group pre: 133.9 ± 4.5, *vs* post: 124.0 ± 4.9 mmHg) when comparisons were made within each group and also between the two groups pre and post-intervention (Figure 6.22). There was no effect of Group, $F(1,31) = 0.363$, $MSE = 230.11$, $p = .551$, Time, $F(1,31) = 3.842$, $MSE = 627.06$, $p = .059$, or interaction of these two factors, $F(1,31) = 1.345$, $MSE = 219.56$, $p = .255$.

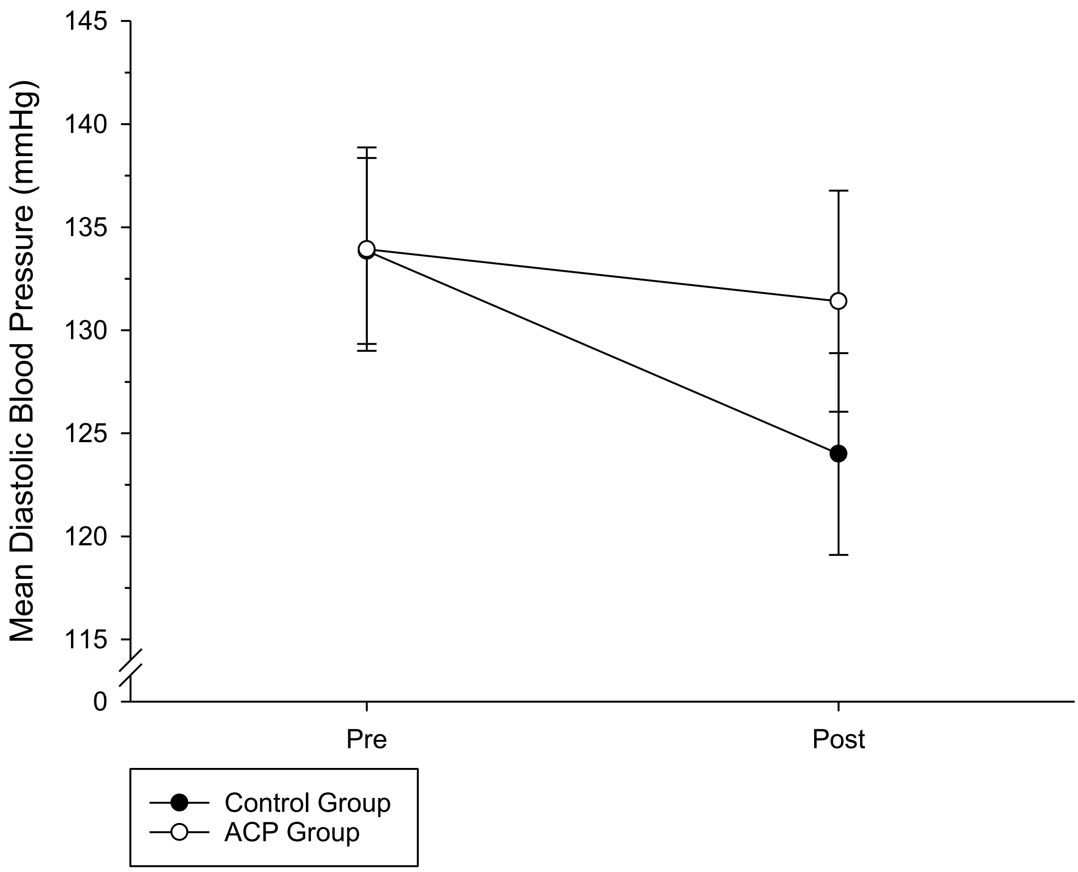

Figure 6.22 DBP during the last two seconds of the SGT +5.5Gz plateau for the Control (n = 18) and ACP (n = 15) group pre and post intervention. Values are group mean ± SE.

SGT Blood Pressure Sub Group Analysis

When reviewing MAP for the sub-group of subjects who completed the +7 Gz plateau there was no significant reduction in the ACP group (pre: 177.4 ± 16.8, *vs* post: 171.4 ± 9.6 mmHg, Control sub-group pre: 182.4 ± 8.1, *vs* post: 175.0 ± 7.4 mmHg) when comparisons were made within each group and also between the two groups pre and post intervention. There was no effect of Group, $F(1,13) = 0.045$, $MSE = 47.56$, $p = .84$, Time, $F(1,13) = 0.789$, $MSE = 457.67$, $p = .39$, and no significant interaction of these two factors, $F(1,13) = 0.047$, $MSE = 27.08$, $p = .83$ (Figure 6.23).

For the +5.5 Gz plateau there was no significant reduction in MAP for ACP sub-group (pre: 163.7 ± 11.8, *vs* post: 146.5 ± 10.1 mmHg, Control sub-group (pre: 155.5 ± 4.0, *vs* post: 154.8 ± 9.8 mmHg) when comparisons were made within each group and also between the two groups pre and post intervention. There was no effect of Group, $F(1,15) = 0.0001$, $MSE = 0.01$, $p = .997$, no effect or Time, $F(1,15) = 1.749$, $MSE = 622.71$, $p = .206$, and no significant interaction of these two factors, $F(1,15) = 1.487$, $MSE = 529.52$, $p = .241$ (Figure 6.23).

There was no reduction in MAP for the ACP sub-group during the +3.0 Gz plateau (pre: 123.5 ± 7.3, *vs* post: 113.2 ± 9.0 mmHg, Control sub-group pre: 128.0 ± 3.7, *vs* post: 124.1 ± 7.2 mmHg) when comparisons were made within each group and also between the two groups pre and post intervention. There was no effect of Group, $F(1,15) = 0.85$, $MSE = 464.16$, $p = .371$, or Time, $F(1,15) = 1.887$, $MSE = 387.88$, $p = .190$, and no significant interaction of these two factors, $F(1,15) = 0382$, $MSE = 78.55$, $p = .546$ (Figure 6.23).

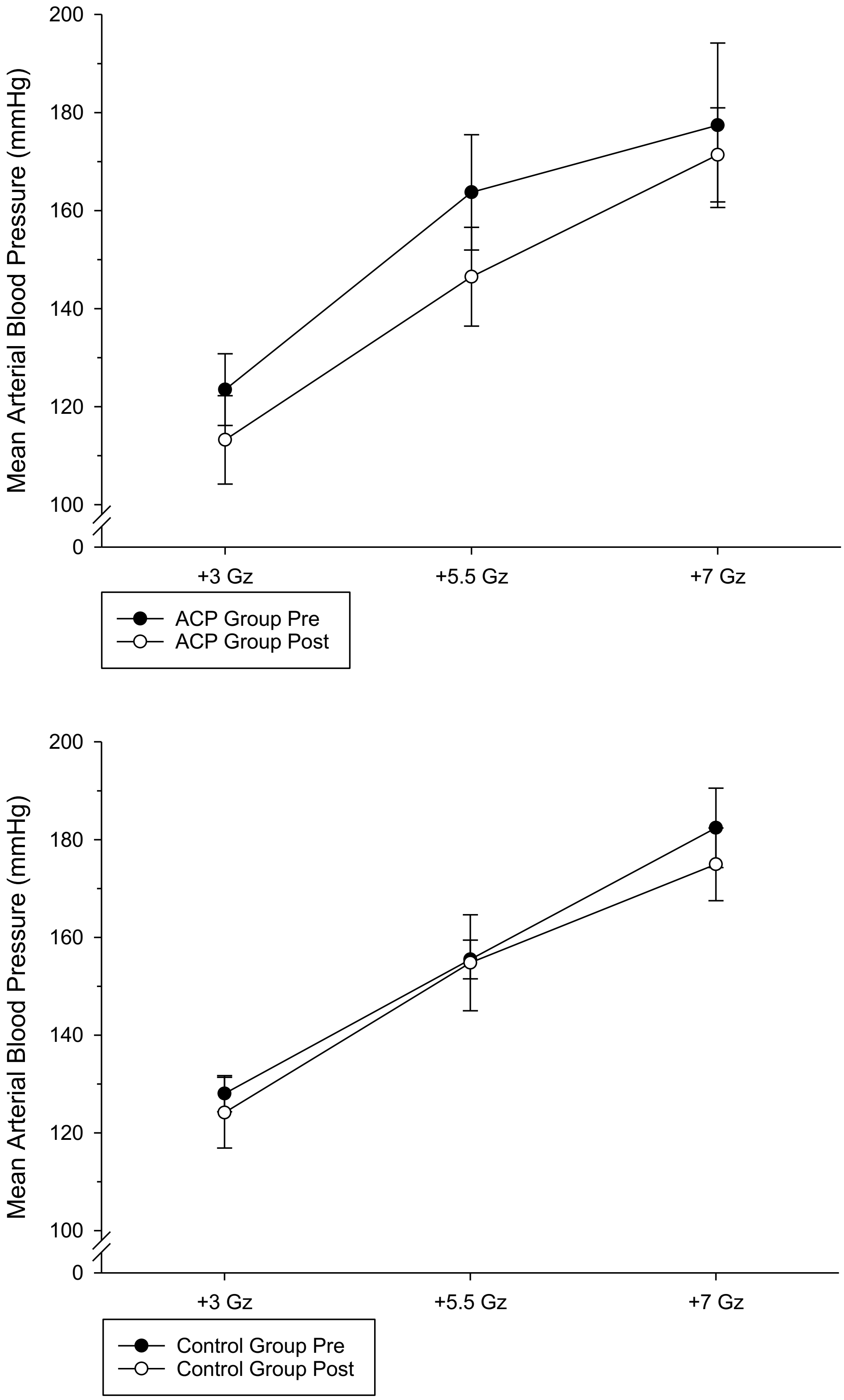

Figure 6.23 MAP for the ACP sub-group (n = 6) and Control sub-group (n = 11) who reached the +7 Gz plateau on both initial (pre intervention) and re-testing of SGT (post intervention). MAP during the last two seconds of the SGT +3 Gz, +5.5 and +7 Gz plateau for each sub-group is shown. Values are sub-group mean ± SE. There was no significant reduction in MAP for the ACP sub-group at the +5.5 Gz plateau.

6.3.4 *Simulated Air Combat Manoeuvre Runs*

During the SACMs the number of +7 Gz peaks completed per subject (maximum of 16) appeared to improve in the ACP group only (pre: 13.9 ± 1.2, *vs* post: 15.4 ± 0.4 peaks per subject) whereas the number for the Control group appeared to reduce (pre: 14.0 ± 1.0, *vs* post: 13.6 ± 1.1 peaks per subject) (Figure 6.24) however this was not significant (p = .583).

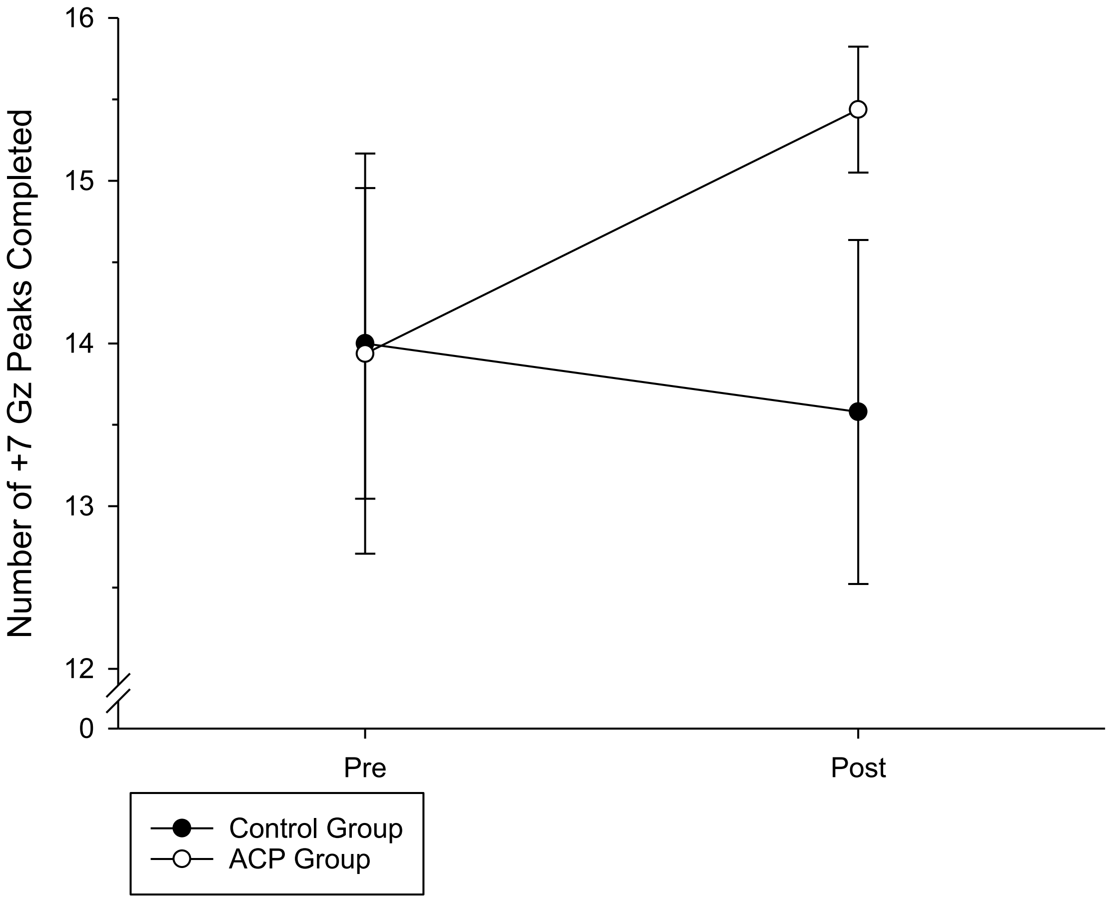

Figure 6.24 Number of +7 Gz peaks per subject (maximum of 16) completed during the SACM runs pre and post intervention. Values are group mean ± SE. The number of SACMs completed by the ACP Group did not significantly increase (p = .583).

All subjects in the ACP group bar one (subject stopped after 12 peaks due to nausea) increased the number of +7 Gz peaks completed per SACM (Figure 6.25) post intervention compared with the Control group (Figure 6.26).

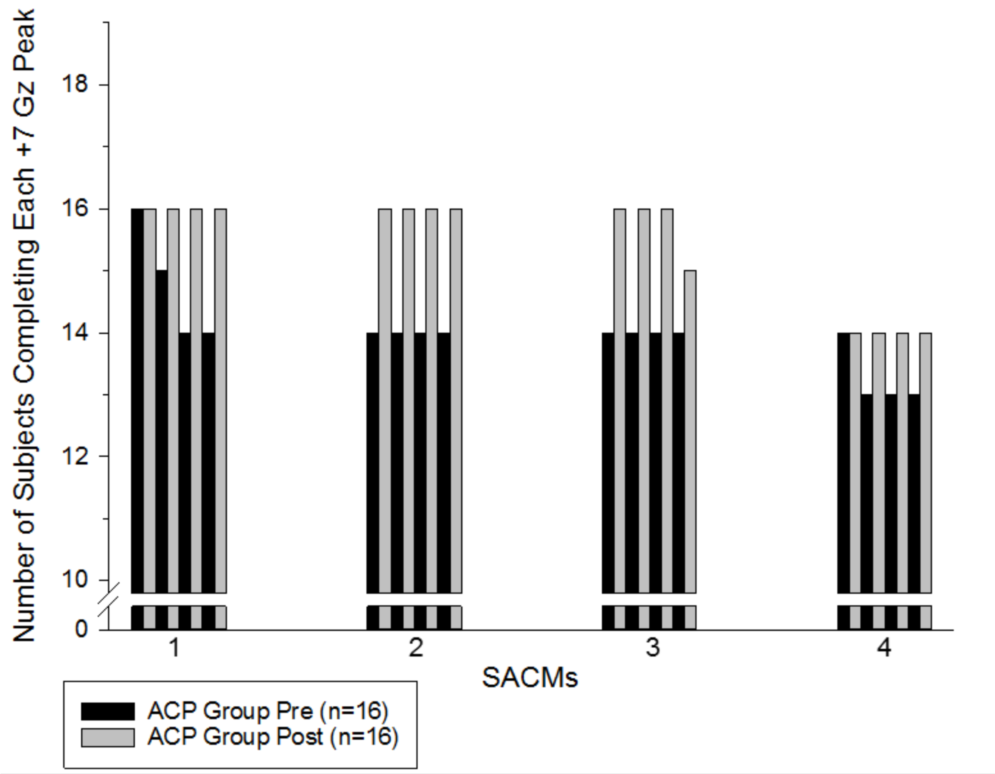

Figure 6.25 Number of +7 Gz peaks completed by subjects in the ACP Group pre and post intervention.

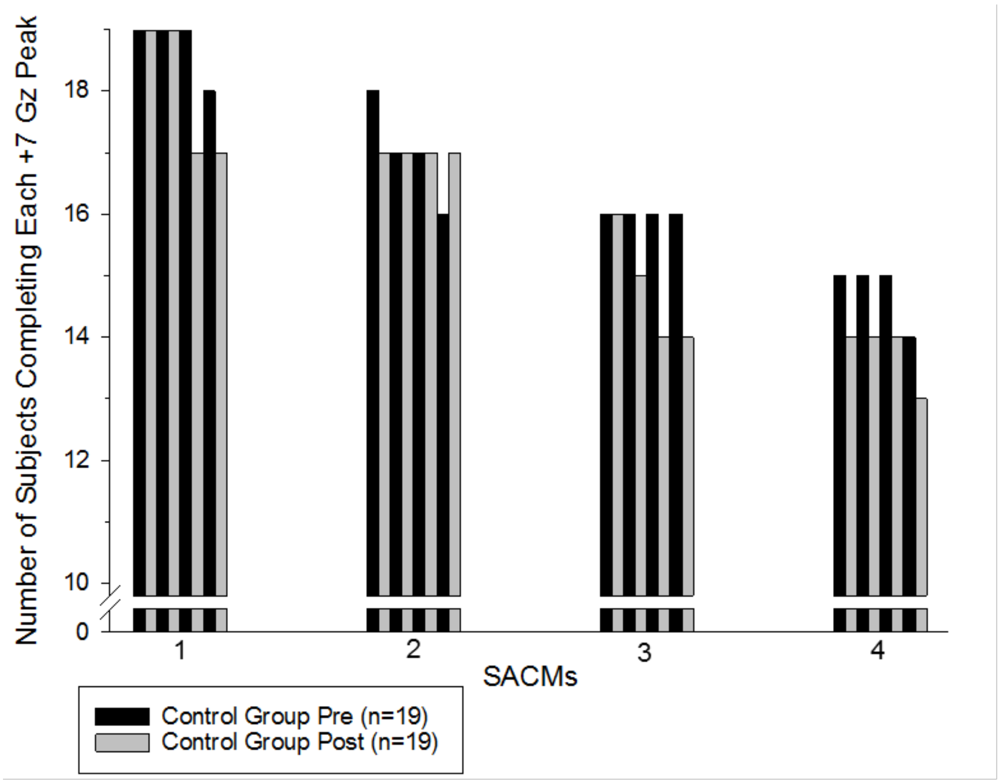

Figure 6.26 Number of +7 Gz peaks completed by subjects in the Control Group pre and post intervention.

Nausea caused one subject in the ACP group (re-test only) and two in the Control group to stop before completing all 4 SACMs (1 on re-testing only). Eleven subjects in the ACP group and 10 in the Control group completed all 16 +7 Gz peaks pre and post. Four subjects in the ACP did not complete all 16 +7 Gz peaks on initial testing with 3 completing 16 peaks on re-testing. Five subjects from the Control group failed to complete all 16 +7 Gz peaks on initial testing, of whom 3 completed 16 peaks on re-testing. A further 4 subjects in the Control group initially completed 16 +7 Gz peaks but failed to repeat this on re-testing. The subjects from each group were subdivided into those who completed all 16 +7 Gz peaks pre and post, and those who did not, and results for each group will be described in greater detail under each section.

SACM Sub Group Analysis – Failed to complete all SACMs

For the subjects in the ACP sub-group who were unable to complete all 16 +7 Gz peaks on initial testing (pre intervention) (n = 4), the number of +7 Gz peaks completed changed post intervention (pre: 7.8 ± 3.6, *vs* post: 14.8 ± 1.3) as did the Control sub-group (n = 5) (pre: 8.4 ± 2.2, *vs* post: 10.4 ± 3.4) (Figure 6.27). However, the small number of subjects precluded the use of any statistical test.

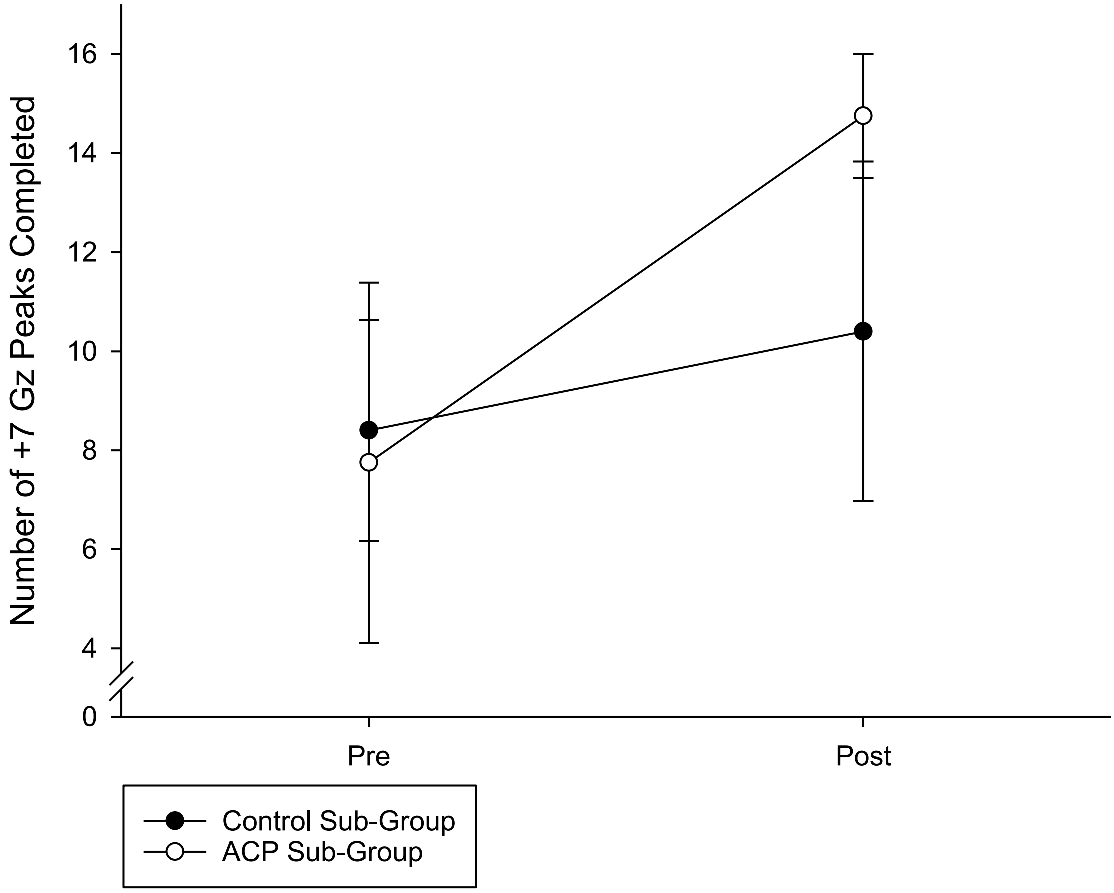

Figure 6.27 Number of +7 Gz peaks per subject (maximum of 16) completed for the ACP and Control Sub-Groups who were unable to complete all 16 peaks on initial testing during the SACM runs. Values are group mean ± SE.

6.3.4.1 *Heart Rate*

The peak HR was recorded during the 1st and 4th +7 Gz peak for each SACM with the mean peak HR calculated for that SACM. The centrifuge changed acceleration at a rate of 1 $G.s^{-1}$. Recovery HR was determined as the mean HR during the immediate 60 s period after each SACM once the centrifuge had returned to an idle speed of +1.5 Gz or less. It is noted that a significant difference existed between the groups for baseline HR; Control group (65.3 ± 1.8 $beats.min^{-1}$) and ACP group (56.4 ± 2.3 $beats.min^{-1}$); $t(34) = 3.070$, $p = .004$.

Mean peak HR during each SACM did not reduce for the ACP group (Table 6.5). There was a significant effect of Group for each SACM but there was no effect of Time and the interaction of Group and Time was not significant (Table 6.6).

	Control Group		ACP Group	
	Pre	Post	Pre	Post
Mean Peak Heart Rate (beats.min^{-1})				
SACM 1 (Control n = 19, ACP n = 16)	152.5 ± 2.8	151.9 ± 2.8	138.1 ± 3.0	138.9 ± 3.1
SACM 2 (Control n = 17, ACP n = 15)	154.1 ± 2.9	150.8 ± 3.1	140.1 ± 3.1	141.9 ± 3.3
SACM 3 (Control n = 16, ACP n = 13)	155.8 ± 3.0	150.2 ± 3.4	141.4 ± 3.3	142.2 ± 3.8
SACM 4 (Control n = 14, ACP n = 12)	156.9 ± 3.5	156.1 ± 3.3	145.0 ± 3.8	144.6 ± 3.6
Mean Recovery Heart Rate (beats.min^{-1})				
SACM 1 (Control n = 19, ACP n = 16)	139.5 ± 3.6	135.4 ± 4.7	124.2 ± 3.9	121.0 ± 5.1
SACM 2 (Control n = 17, ACP n = 14)	144.3 ± 3.9	144.5 ± 4.2	125.1 ± 4.3	130.6 ± 4.6
SACM 3 (Control n = 15, ACP n = 13)	151.2 ± 4.1	146.2 ± 4.4	131.3 ± 4.4	132.4 ± 4.7
SACM 4 (Control n = 14, ACP n = 12)	146.2 ± 5.4	140.6 ± 4.7	125.2 ± 5.8	126.8 ± 5.0

Table 6.5 Mean peak HR and mean recovery HR for the Control and ACP groups pre and post intervention. Values are mean ± SE.

Mean recovery HR following each SACM did not reduce for the ACP group (Table 6.5). There was a significant effect of Group for each SACM but there was no effect of Time and the interaction of Group and Time was not significant (Table 6.6).

	Effect of Group	Effect of Time	Interaction of Group and Time
Mean Peak Heart Rate (beats.min^{-1})			
SACM 1 (Control n = 19, ACP n = 16)	$F(1,33) = 13.695$, $MSE = 3272.55$, $p = .001$*	$F(1,33) = 0.004$, $MSE = 0.23$, $p = .952$	$F(1,33) = 0.13$, $MSE = 8.02$, $p = .721$
SACM 2 (Control n = 17, ACP n = 15)	$F(1,30) = 8.26$, $MSE = 2094.43$, $p = .007$*	$F(1,30) = 0.184$, $MSE = 8.61$, $p = .671$	$F(1,30) = 2.188$, $MSE = 102.64$, $p = .150$
SACM 3 (Control n = 16, ACP n = 13)	$F(1,27) = 6.583$, $MSE = 1788.26$, $p = .016$*	$F(1,27) = 1.409$, $MSE = 81.89$, $p = .246$	$F(1,27) = 2.555$, $MSE = 148.48$, $p = .122$
SACM 4 (Control n = 14, ACP n = 12)	$F(1,24) = 6.893$, $MSE = 1758.97$, $p = .015$*	$F(1,24) = 0.069$, $MSE = 4.60$, $p = .796$	$F(1,24) = 0.009$, $MSE = 0.60$, $p = .925$
Mean Recovery Heart Rate (beats.min^{-1})			
SACM 1 (Control n = 19, ACP n = 16)	$F(1,33) = 6.899$, $MSE = 3843.35$, $p = .013$*	$F(1,33) = 2.468$, $MSE = 228.45$, $p = .126$	$F(1,33) = 0.041$, $MSE = 3.80$, $p = .841$
SACM 2 (Control n = 17, ACP n = 14)	$F(1,29) = 9.614$, $MSE = 4184.16$, $p = .004$*	$F(1,29) = 1.108$, $MSE = 123.76$, $p = .301$	$F(1,29) = 0.949$, $MSE = 105.95$, $p = .338$
SACM 3 (Control n = 15, ACP n = 13)	$F(1,26) = 8.932$, $MSE = 3934.45$, $p = .006$*	$F(1,26) = 0.51$, $MSE = 51.19$, $p = .482$	$F(1,26) = 1.328$, $MSE = 133.34$, $p = .260$
SACM 4 (Control n = 14, ACP n = 12)	$F(1,24) = 7.324$, $MSE = 3918.55$, $p = .012$*	$F(1,24) = 0.292$, $MSE = 49.44$, $p = .594$	$F(1,24) = 1.01$, $MSE = 171.01$, $p = .325$

Table 6.6 Results of 2x2 mixed ANOVA for the effects of Group and Time, and the interaction between Group and Time for mean peak HR and mean recovery HR for each SACM pre and post intervention. *The ACP group had a significantly lower resting heart rate ($p < .004$) compared to the Control group resulting in a significant effect of Group. There was no effect of Time, and the interaction of Group and Time was not significant for any of the measurements.

SACM Sub Group Analysis – Completed all SACMs

For the ACP sub-group (n = 11) who completed all 16 +7 Gz peaks pre and post intervention, mean peak HR during the SACMs did not reduce and neither did mean recovery HR (Table 6.7) compared with the Control sub-group (n = 10). There was a significant effect of Group (the ACP sub-group had a significantly lower initial resting heart rate (p < .004), but there was no effect of Time, and the interaction of Group and Time was not significant for any of the SACMs (Table 6.8).

	Control Sub-Group (Completed 16 +7 Gz Peaks) (n = 10)		ACP Sub-Group (Completed 16 +7 Gz Peaks) (n = 11)	
	Pre	Post	Pre	Post
Mean Peak Heart Rate (beats.min^{-1})				
SACM 1	150.0 ± 4.1	149.4 ± 3.8	136.5 ± 3.9	133.1 ± 3.6
SACM 2	152.8 ± 4.0	149.8 ± 4.0	136.3 ± 4.0	135.9 ± 4.0
SACM 3	154.5 ± 4.1	150.3 ± 3.8	138.8 ± 4.1	137.8 ± 3.8
SACM 4	157.9 ± 4.4	156.7 ± 4.0	144.0 ± 4.4	141.5 ± 4.0
Mean Recovery Heart Rate (beats.min^{-1})				
SACM 1	140.0 ± 3.3	137.3 ± 4.1	116.8 ± 4.3	113.0 ± 4.9
SACM 2	141.3 ± 3.7	141.5 ± 3.6	119.0 ± 5.1	122.2 ± 4.8
SACM 3	148.5 ± 4.1	145.3 ± 4.3	127.1 ± 4.9	127.9 ± 4.3
SACM 4	148.3 ± 5.5	140.5 ± 4.4	122.0 ± 6.1	120.7 ± 5.0

Table 6.7 Mean peak HR and mean recovery HR for the Control and ACP sub-groups pre and post intervention. Values are mean ± SE. *The ACP sub-group had a significantly lower resting heart rate (p < .004) compared to the Control sub-group. There were no other significant differences between the groups for any of the measurements.

	Effect of Group	Effect of Time	Interaction of Group and Time
Sub-Group Mean Peak Heart Rate (beats.min^{-1})			
SACM 1 (Control n = 10, ACP n = 11)	$F(1,19) = 9.123$, $MSE = 2325.09$, $p = .007$*	$F(1,19) = 0.695$, $MSE = 42.35$, $p = .415$	$F(1,19) = 0.311$, $MSE = 18.98$, $p = .583$
SACM 2 (Control n = 10, ACP n = 10)	$F(1,18) = 8.721$, $MSE = 2305.99$, $p = .009$*	$F(1,18) = 0.613$, $MSE = 31.13$, $p = .444$	$F(1,18) = 0.329$, $MSE = 16.73$, $p = .573$
SACM 3 (Control n = 10, ACP n = 10)	$F(1,18) = 7.62$, $MSE = 2005.05$, $p = .013$*	$F(1,18) = 1.348$, $MSE = 65.98$, $p = .261$	$F(1,18) = 0.549$, $MSE = 26.87$, $p = .468$
SACM 4 (Control n = 10, ACP n = 10)	$F(1,18) = 7.491$, $MSE = 2126.79$, $p = .014$*	$F(1,18) = 0.528$, $MSE = 34.69$, $p = .477$	$F(1,18) = 0.066$, $MSE = 4.32$, $p = .801$
Sub-Group Mean Recovery Heart Rate (beats.min^{-1})			
SACM 1 (Control n = 10, ACP n = 11)	$F(1,19) = 18.736$, $MSE = 5925.76$, $p = .0001$*	$F(1,19) = 1.9$, $MSE = 112.74$, $p = .184$	$F(1,19) = 0.052$, $MSE = 3.09$, $p = .822$
SACM 2 (Control n = 10, ACP n = 9)	$F(1,17) = 12.314$, $MSE = 4085.44$, $p = .003$*	$F(1,17) = 0.011$, $MSE = 1.10$, $p = .917$	$F(1,17) = 0.369$, $MSE = 36.56$, $p = .548$
SACM 3 (Control n = 10, ACP n = 10)	$F(1,18) = 11.619$, $MSE = 3756.61$, $p = .003$*	$F(1,18) = 0.144$, $MSE = 14.52$, $p = .709$	$F(1,18) = 0.373$, $MSE = 37.56$, $p = .549$
SACM 4 (Control n = 10, ACP n = 10)	$F(1,18) = 11.922$, $MSE = 5308.61$, $p = .003$*	$F(1,18) = 1.188$, $MSE = 207.54$, $p = .290$	$F(1,18) = 0.628$, $MSE = 109.66$, $p = .438$

Table 6.8 Results of the 2x2 mixed ANOVA for the effects of Group and Time, and the interaction between Group and Time for sub-group mean peak HR and sub-group mean recovery HR for each SACM pre and post intervention. *The ACP sub-group had a significantly lower initial resting heart rate ($p < .004$) compared to the Control group resulting in a significant effect of Group. There was no effect of Time, and the interaction of Group and Time was not significant for any of the measurements.

6.3.4.2 *Blood Pressure*

It was not possible to obtain consistent and accurate measures of BP during the +7 Gz peaks due to a loss of signal (Figure 6.28).

6.3.4.3 *Rating of Perceived Exertion (RPE)*

Subjects provided a RPE score out of 10 after each SACM (Table 6.9) and the cumulative RPE for all 4 SACMs was calculated (maximum score of 40) pre and post intervention. RPE reduced for both groups (ACP group pre: 30.3 ± 1.3, *vs* post: 28.0 ± 1.2, Control group pre: 29.4 ± 1.3, *vs* post: 27.3 ± 1.1). There was no effect of Group, $F(1,32) = 0.26$, $MSE = 10.62$, $p = .614$, there was a significant effect of Time, $F(1,32) = 9.064$, $MSE = 80.55$, $p = .005$, but there was no significant interaction of these two factors, $F(1,32) = 0.009$, $MSE = 0.08$, $p = .924$. Post-hoc tests showed that RPE significantly reduced for both groups (ACP group: $p = .041$, Control group: $p = .041$).

	Control Group		ACP Group	
	Pre	Post	Pre	Post
SACM 1	6.4 ± 0.4	6.0 ± 0.4	6.6 ± 0.3	6.2 ± 0.3
SACM 2	7.1 ± 0.4	6.5 ± 0.3	7.1 ± 0.3	6.9 ± 0.3
SACM 3	7.8 ± 0.4	7.0 ± 0.4	7.7 ± 0.3	7.3 ± 0.3
SACM 4	8.3 ± 0.4	7.5 ± 0.4	8.3 ± 0.3	7.9 ± 0.4

Table 6.9 RPE for the Control and ACP groups pre and post intervention. Values are mean ± SE.

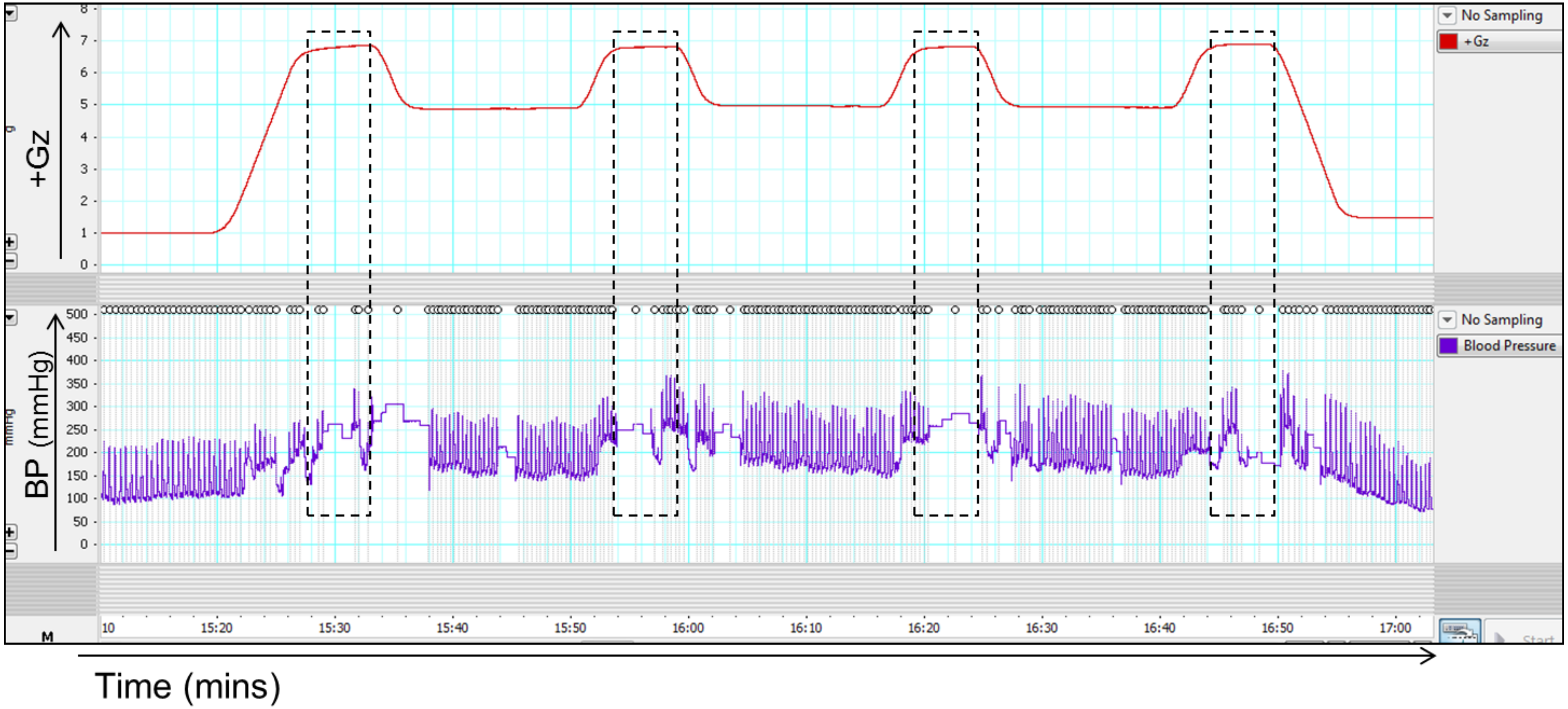

Figure 6.28 Raw BP trace recorded during a SACM demonstrating the loss of signal during the +7 Gz peaks (indicated by dashed box) which returns during the +5 Gz plateaus.

SACM Sub Group Analysis – Completed all SACMs

RPE also appeared to reduce for both sub-groups pre and post intervention (ACP sub-group pre: 28.6 ± 1.2, *vs* post: 26.6 ± 0.9, Control sub-group pre: 27.2 ± 1.2, *vs* post: 25.4 ± 0.9). There was no effect of Group, $F(1,19) = 0.831$, $MSE = 16.25$, $p = .373$, there was a significant effect of Time, $F(1,19) = 8.575$, $MSE = 37.82$, $p = .009$, but there was no significant interaction of these two factors, $F(1,19) = 0.024$, $MSE = 0.11$, $p = .879$. Post-hoc tests showed that the ACP sub-group had significantly reduced ($p = .038$).

SACM Sub Group Analysis – Failed to complete all SACMs

For the subjects in the ACP sub-group who were unable to complete all 16 +7 Gz peaks on initial testing (pre intervention) (n = 4), RPE also reduced post intervention (pre: 36.0 ± 3.2, *vs* post: 32.5 ± 2.8) as it did for the Control sub-group (n = 4) (pre: 33.8 ± 3.2, *vs* post: 31.3 ± 2.8).

6.3.4.4 *Post Acceleration O_2 Composition*

The $\dot{V}O_2$ from the expired air collected after SACM 2 for the ACP group was unchanged (pre: 10.2 ± 0.5, *vs* post: 11.0 ± 0.6 $ml.min.kg^{-1}$) as was the Control group (pre: 12.5 ± 0.5, *vs* post: 11.8 ± 0.6 $ml.min.kg^{-1}$). There was a significant effect of Group, $F(1,28) = 5.222$, $MSE = 37.19$, $p = .03$, no effect of Time, $F(1,28) = 0.006$, $MSE = 0.01$, $p = .939$, but there was a significant interaction of these two factors, $F(1,28) = 5.953$, $MSE = 7.58$, $p = .021$. Post-hoc tests were not significant at the .05 level of significance (Figure 6.29).

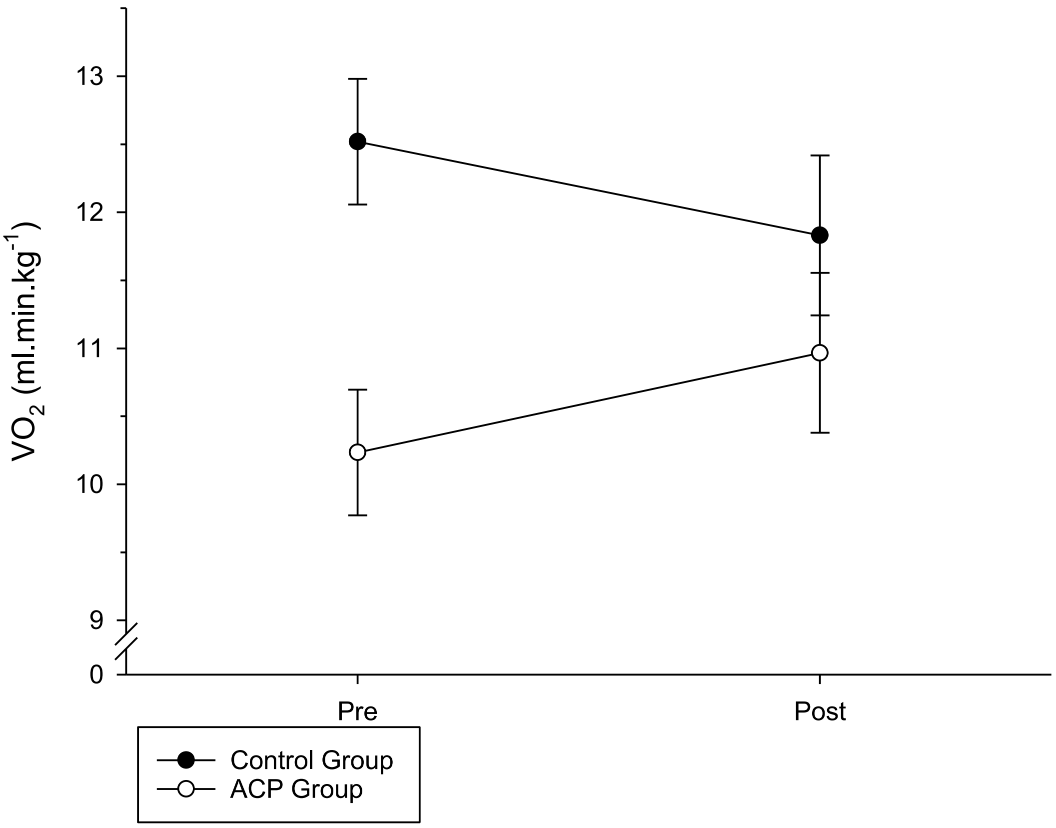

Figure 6.29 Post acceleration $\dot{V}O_2$ collected following SACM 2. Values are group mean ± SE.

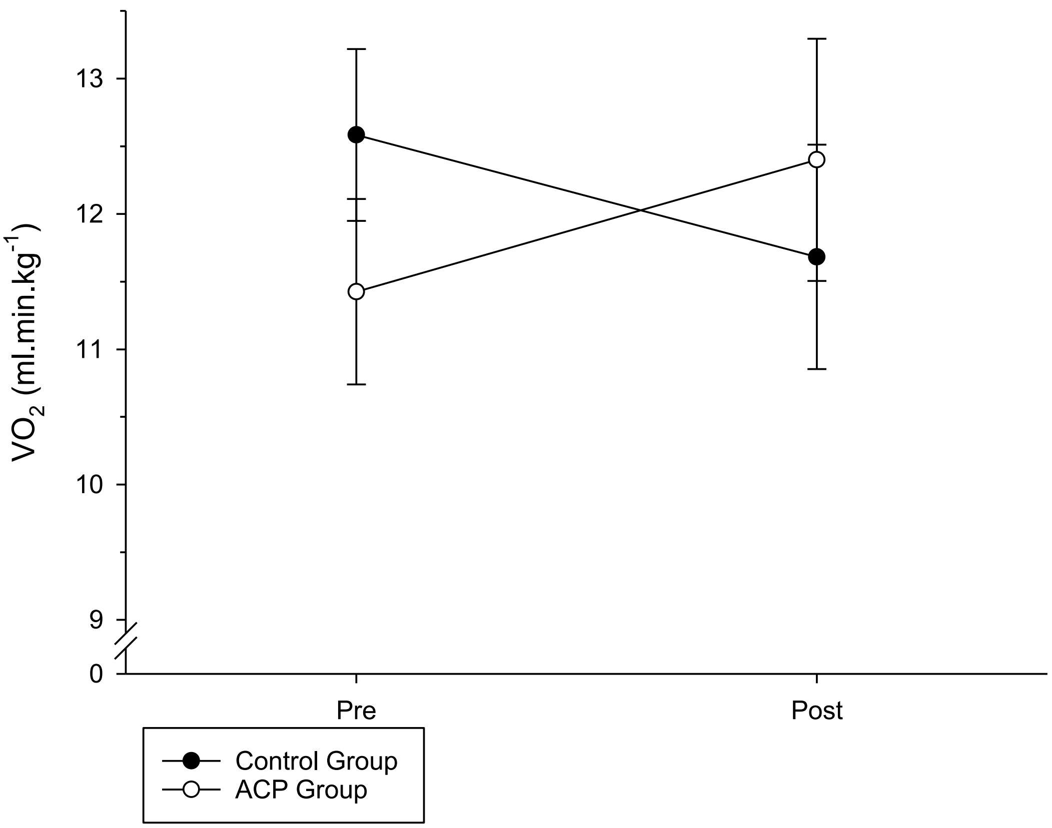

Figure 6.30 Post acceleration $\dot{V}O_2$ collected following SACM 4. Values are group mean ± SE.

The $\dot{V}O_2$ collected after SACM 4 for the ACP group also appeared to increase (pre: 11.4 ± 0.7, *vs* post: 12.4 ± 0.9 ml.min.kg^{-1}) compared with the Control group which reduced (pre: 12.6 ± 0.6, *vs* post: 11.7 ± 0.8 ml.min.kg^{-1}). For $\dot{V}O_2$ collected after SACM 4, there was no effect of Group, $F(1,24) = 0.062$, $MSE = 0.63$, $p = .806$, no effect of Time, $F(1,24) = 0.003$, $MSE = 0.02$, $p = .954$, and the interaction of these two factors was not significant, $F(1,24) = 2.256$, $MSE = 11.38$, $p = .146$ (Figure 6.30).

SACM Sub Group Analysis – Completed all SACMs

$\dot{V}O_2$ collected after SACM 2 for both sub-groups who completed all SACMs was unchanged (ACP sub-group pre: 9.9 ± 0.5, *vs* post: 10.3 ± 0.6 ml.min.kg^{-1}, Control sub-group pre: 12.3 ± 0.6, *vs* post: 11.6 ± 0.7 ml.min.kg^{-1}). There was a significant effect of Group, $F(1,18) = 5.519$, $MSE = 32.62$, $p = .030$, no effect of Time, $F(1,18) = 0.138$, $MSE = 0.12$, $p = .714$, and the interaction of these two factors was not significant, $F(1,18) = 3.381$, $MSE = 3.02$, $p = .083$. Post-hoc tests were not significant.

$\dot{V}O_2$ collected after SACM 4 for both sub-groups who completed all SACMs was again unchanged (ACP sub-group pre: 11.4 ± 0.7, *vs* post: 12.2 ± 1.0 ml.min.kg^{-1}, Control sub-group pre: 13.4 ± 0.8, *vs* post: 12.2 ± 0.8 ml.min.kg^{-1}). There was no effect of Group, $F(1,18) = 1.037$, $MSE = 10.32$, $p = .322$, no effect of Time, $F(1,18) = 0.102$, $MSE = 0.63$, $p = .753$, and the interaction of these two factors was not significant, $F(1,18) = 1.599$, $MSE = 9.76$, $p = .222$.

SACM Sub Group Analysis – Failed to complete all SACMs

For the subjects in the ACP sub-group who were unable to complete all 16 +7 Gz peaks on initial testing (pre intervention) (n = 4), $\dot{V}O_2$ collected after SACM 2 also appeared to increase (pre: 11.2 ± 1.8, *vs* post: 13.7 ± 0.8 ml.min.kg^{-1}) compared with the Control sub-group which reduced (n = 3) (pre: 13.7 ± 0.7, *vs* post: 12.7 ± 0.7 ml.min.kg^{-1}).

$\dot{V}O_2$ collected after SACM 4 again appeared to increase for the ACP sub-group who were unable to complete all 16 +7 Gz peaks on initial testing (pre intervention) (n = 3), (pre: 11.5 ± 1.9, *vs* post: 14.1 ± 0.8 ml.min.kg^{-1}) compared with the Control sub-group which reduced (n = 3) (pre: 11.1 ± 0.1, *vs* post: 12.8 ± 0.4 ml.min.kg^{-1}).

6.3.4.5 *Blood Lactate*

Blood lactate 180 s after completion of SACM 4 for both groups was unchanged (ACP group pre: 5.6 ± 0.5 mmol.L^{-1}, *vs* post: 5.9 ± 0.7 mmol.L^{-1}, Control group pre: 6.4 ± 0.5 mmol.L^{-1}, *vs* post: 7.0 ± 0.6 mmol.L^{-1}). There no effect of Group, $F(1,32) = 1.745$, $MSE = 16.17$, $p = .196$, no effect of Time, $F(1,32) = 1.477$, $MSE = 3.72$, $p = .233$, and no significant interaction of these two factors, $F(1,32) = 0.116$, $MSE = 0.29$, $p = .736$.

SACM Sub Group Analysis – Completed all SACMs

Blood lactate 180 s after SACM 4 for the ACP sub-groups who completed all SACMs was unchanged (pre: 5.3 ± 0.7, *vs* post: 5.3 ± 0.8 mmol.L^{-1}) compared with the Control group which appeared to increase (pre: 5.8 ± 0.7, *vs* post: 6.4 ± 0.8 mmol.L^{-1}). There was no effect of Group, $F(1,19) = 0.776$, $MSE = 6.72$, $p = .390$, no effect of Time, $F(1,19) = 0.374$, $MSE = 0.89$, $p = .548$, and the interaction of these two factors was not significant, $F(1,19) = 0.422$, $MSE = 1.00$, $p = .524$.

SACM Sub Group Analysis – Failed to complete all SACMs

For the subjects in both sub-groups who were unable to complete all 16 +7 Gz peaks on initial testing, blood lactate collected after SACM 4 appeared to increase (ACP sub-group (n = 4) pre: 6.3 ± 0.9, *vs* post: 7.7 ± 1.2 $mmol.L^{-1}$, Control sub-group (n = 4) (pre: 6.8 ± 0.9, *vs* post: 8.5 ± 1.2 $mmol.L^{-1}$).

6.3.4.6 *EMG*

Quadriceps, hamstring and calf muscle EMG (% RMS) during each SACM did not reduce in the ACP group post intervention (Table 6.10). There was no effect of Group, Time, and the interaction of Group and Time was not significant for any of the muscles during any of the SACMs post intervention (Table 6.11).

	Control Group		ACP Group	
	Pre	Post	Pre	Post
Quadriceps Muscle EMG (% RMS)				
SACM 1 (Control n = 18 ACP n = 16)	25.84 ± 3.44	27.47 ± 4.31	34.83 ± 3.65	29.66 ± 4.57
SACM 2 (Control n = 16 ACP n = 16)	24.81 ± 4.12	26.09 ± 4.15	29.73 ± 4.12	29.54 ± 4.15
SACM 3 (Control n = 16 ACP n = 15)	23.41 ± 3.85	26.69 ± 3.90	27.79 ± 3.98	27.91 ± 4.02
SACM 4 (Control n = 15 ACP n = 12)	30.29 ± 5.24	27.93 ± 4.27	28.31 ± 5.86	29.03 ± 4.77
Hamstring Muscle EMG (% RMS)				
SACM 1 (Control n = 15 ACP n = 15)	27.09 ± 4.63	26.30 ± 4.90	30.05 ± 4.63	26.72 ± 4.90
SACM 2 (Control n = 14 ACP n = 15)	23.21 ± 4.37	21.35 ± 3.98	23.55 ± 4.22	24.87 ± 3.85
SACM 3 (Control n = 14 ACP n = 13)	24.00 ± 4.79	21.82 ± 4.58	21.55 ± 4.97	25.59 ± 4.76
SACM 4 (Control n = 12 ACP n = 10)	24.42 ± 5.83	17.01 ± 3.93	25.57 ± 6.38	20.37 ± 4.30
Calf Muscle EMG (% RMS)				
SACM 1 (Control n = 18 ACP n = 14)	19.04 ± 2.81	17.64 ± 2.98	17.65 ± 3.19	21.59 ± 3.38
SACM 2 (Control n = 16 ACP n = 14)	19.31 ± 2.87	17.14 ± 3.14	14.68 ± 3.07	20.91 ± 3.36
SACM 3 (Control n = 16 ACP n = 13)	19.43 ± 3.39	19.06 ± 3.98	17.51 ± 3.76	20.13 ± 4.42
SACM 4 (Control n = 15 ACP n = 11)	23.78 ± 3.74	19.29 ± 3.16	18.22 ± 4.37	18.12 ± 3.69

Table 6.10 Quadriceps, hamstring and calf EMG (% RMS) for the Control and ACP groups pre and post intervention. Values are mean ± SE. There were no significant differences between the groups for any of the measurements.

	Effect of Group	Effect of Time	Interaction of Group and Time
Quadriceps Muscle EMG (% RMS)			
SACM 1 (Control n = 18, ACP n = 16)	$F(1,32) = 1.370$, $MSE = 528.45$, $p = .25$	$F(1,32) = 0.329$, $MSE = 52.94$, $p = .57$	$F(1,32) = 1.217$, $MSE = 195.96$, $p = .278$
SACM 2 (Control n = 16, ACP n = 16)	$F(1,30) = 0.751$, $MSE = 280.56$, $p = .393$	$F(1,30) = 0.028$, $MSE = 4.84$, $p = .869$	$F(1,30) = 0.05$, $MSE = 8.70$, $p = .824$
SACM 3 (Control n = 16, ACP n = 15)	$F(1,29) = 0.343$, $MSE = 121.68$, $p = .563$	$F(1,29) = 0.359$, $MSE = 44.95$, $p = .554$	$F(1,29) = 0.31$, $MSE = 38.84$, $p = .582$
SACM 4 (Control n = 15, ACP n = 12)	$F(1,25) = 0.005$, $MSE = 2.53$, $p = .943$	$F(1,25) = 0.046$, $MSE = 8.91$, $p = .832$	$F(1,25) = 0.163$, $MSE = 31.72$, $p = .69$
Hamstring Muscle EMG (% RMS)			
SACM 1 (Control n = 15, ACP n = 15)	$F(1,28) = 0.081$, $MSE = 42.84$, $p = .779$	$F(1,28) = 0.424$, $MSE = 63.86$, $p = .52$	$F(1,28) = 0.16$, $MSE = 24.19$, $p = .692$
SACM 2 (Control n = 14, ACP n = 15)	$F(1,27) = 0.138$, $MSE = 53.83$, $p = .713$	$F(1,27) = 0.011$, $MSE = 1.10$, $p = .917$	$F(1,27) = 0.369$, $MSE = 36.56$, $p = .548$
SACM 3 (Control n = 14, ACP n = 13)	$F(1,25) = 0.012$, $MSE = 5.85$, $p = .913$	$F(1,25) = 0.086$, $MSE = 11.76$, $p = .772$	$F(1,25) = 0.955$, $MSE = 130.59$, $p = .338$
SACM 4 (Control n = 12, ACP n = 10)	$F(1,20) = 0.168$, $MSE = 55.60$, $p = .686$	$F(1,20) = 1.656$, $MSE = 433.56$, $p = .213$	$F(1,20) = 0.051$, $MSE = 13.30$, $p = .824$
Calf Muscle EMG (% RMS)			
SACM 1 (Control n = 18, ACP n = 14)	$F(1,30) = 0.11$, $MSE = 25.80$, $p = .743$	$F(1,30) = 0.377$, $MSE = 25.35$, $p = .544$	$F(1,30) = 1.675$, $MSE = 112.63$, $p = .205$
SACM 2 (Control n = 16, ACP n = 14)	$F(1,28) = 0.012$, $MSE = 2.78$, $p = .915$	$F(1,28) = 1.181$, $MSE = 61.75$, $p = .287$	$F(1,28) = 5.042$, $MSE = 263.70$, $p = .033$*
SACM 3 (Control n = 16, ACP n = 13)	$F(1,27) = 0.008$, $MSE = 2.59$, $p = .930$	$F(1,27) = 0.164$, $MSE = 18.12$, $p = .689$	$F(1,27) = 0.291$, $MSE = 32.23$, $p = .594$
SACM 4 (Control n = 15, ACP n = 11)	$F(1,24) = 0.514$, $MSE = 144.02$, $p = .480$	$F(1,24) = 0.842$, $MSE = 66.75$, $p = .368$	$F(1,24) = 0.770$, $MSE = 61.06$, $p = .389$

Table 6.11 Results of 2x2 mixed ANOVA for the effects of Group and Time, and the interaction between Group and Time for quadriceps, hamstring and calf muscle EMG during each SACM pre and post intervention. *The ACP group had a significantly higher calf muscle EMG ($p = .030$) during SACM 2. There was no other effect of Group or Time, and the interaction of Group and Time was not significant for any of the other measurements.

SACM Sub Group Analysis – Completed all SACMs

For the ACP sub-group (n = 11) who completed all 16 +7 Gz peaks pre and post, EMG during each SACM did not reduce compared with the Control sub-group (n = 10) (Table 6.12).

	Control Sub-Group (Completed 16 +7 Gz Peaks) (n = 10)		ACP Sub-Group (Completed 16 +7 Gz Peaks) (n = 11)	
	Pre	Post	Pre	Post
Quadriceps Muscle EMG (% RMS)				
SACM 1	26.55 ± 4.54	27.00 ± 6.00	36.08 ± 4.33	24.25 ± 5.72
SACM 2	26.80 ± 5.71	26.32 ± 5.32	29.62 ± 5.17	24.10 ± 4.81
SACM 3	24.99 ± 3.88	26.36 ± 5.57	27.15 ± 4.97	23.63 ± 5.10
SACM 4	36.23 ± 7.71	27.61 ± 6.30	29.16 ± 6.61	23.94 ± 5.57
Hamstring Muscle EMG (% RMS)				
SACM 1	27.90 ± 7.23	31.23 ± 7.65	31.52 ± 6.29	31.37 ± 5.93
SACM 2	23.36 ± 7.21	24.17 ± 6.33	25.34 ± 5.75	28.37 ± 5.51
SACM 3	23.09 ± 8.17	26.17 ± 7.53	23.18 ± 7.20	29.01 ± 6.64
SACM 4	23.72 ± 10.01	14.82 ± 5.18	30.29 ± 9.27	22.93 ± 4.79
Calf Muscle EMG (% RMS)				
SACM 1	15.17 ± 2.58	21.22 ± 4.32	20.38 ± 3.96	24.08 ± 4.99
SACM 2	17.69 ± 3.07	19.40 ± 3.94	17.40 ± 2.79	25.16 ± 4.46
SACM 3	17.02 ± 3.30	23.04 ± 7.69	20.56 ± 3.31	23.15 ± 4.58
SACM 4	19.73 ± 4.90	21.93 ± 5.13	21.35 ± 3.64	20.11 ± 3.05

Table 6.12 Quadriceps, hamstring and calf EMG (% RMS) for the Control and ACP sub-groups pre and post intervention. Values are mean ± SE. There were no significant differences between the groups for any of the measurements.

6.3.4.7 *Foot Pedal Force*

Mean foot pedal force was calculated for each SACM (Table 6.13) and the ACP group had a significantly higher mean foot pedal force (p = .003) for SACM 1 pre intervention. There was no other effect of Group, Time, and the interaction of Group and Time was not significant for mean foot pedal force during any of the other SACMs (Table 6.14).

	Control Group		ACP Group	
	Pre	Post	Pre	Post
Mean Foot Pedal Force (N)				
SACM 1 (Control n = 18 ACP n = 16)	2283.79 ± 142.20	2375.75 ± 169.90	2862.92 ± 150.82*	2644.98 ± 180.21
SACM 2 (Control n = 16 ACP n = 16)	2178.52 ± 175.73	2326.96 ± 171.17	2725.57 ± 175.73	2604.91 ± 171.17
SACM 3 (Control n = 16 ACP n = 15)	2092.41 ± 169.39	2282.28 ± 167.45	2664.56 ± 174.95	2516.70 ± 172.94
SACM 4 (Control n = 15 ACP n = 12)	2312.01 ± 225.24	2374.35 ± 165.16	2795.70 ± 251.83	2519.15 ± 184.65

Table 6.13 Mean foot pedal force (N) for the Control and ACP groups. Values are mean ± SE. *The ACP group had a significantly higher mean foot pedal force (p = .003) for SACM 1 pre intervention. There were no other significant differences between the groups.

	Effect of Group	Effect of Time	Interaction of Group and Time
Mean Foot Pedal Force (N)			
SACM 1 (Control n = 18, ACP n = 16)	$F(1,32) = 4.296$, $MSE = 3048354.60$, $p = .046$*	$F(1,32) = 0.386$, $MSE = 67186.10$, $p = .539$	$F(1,32) = 2.339$, $MSE = 406824.87$, $p = .136$
SACM 2 (Control n = 16, ACP n = 16)	$F(1,30) = 3.636$, $MSE = 2722491.75$, $p = .066$	$F(1,30) = 0.014$, $MSE = 3083.58$, $p = .905$	$F(1,30) = 1.353$, $MSE = 289659.24$, $p = .254$
SACM 3 (Control n = 16, ACP n = 15)	$F(1,29) = 3.562$, $MSE = 2518341.28$, $p = .069$	$F(1,29) = 0.034$, $MSE = 6831.25$, $p = .855$	$F(1,29) = 2.200$, $MSE = 441521.95$, $p = .149$
SACM 4 (Control n = 15, ACP n = 12)	$F(1,25) = 1.47$, $MSE = 1316677.47$, $p = .237$	$F(1,25) = 0.557$, $MSE = 152950.46$, $p = .462$	$F(1,25) = 1.395$, $MSE = 382829.35$, $p = .249$

Table 6.14 Results of 2x2 mixed ANOVA for the effects of Group and Time, and the interaction between Group and Time for mean foot pedal force during each SACM. *The ACP group had a significantly higher mean foot pedal force ($p = .003$) for SACM 1 pre intervention. There was no other effect of Group, Time, and the interaction of Group and Time was not significant for any of the other SACMs.

Following a 5 min rest period after completion of SACM 4, subjects repeated the procedure to maintain 30% of the maximum force. Only those subjects who completed all 16 +7 Gz peaks were included in this analysis. For the ACP sub-group (n = 11) who completed all 16 +7 Gz peaks pre and post, time to failure for 30% of maximum leg push (s) after completion of the SACMs appeared to increase compared with the Control sub-group (n = 10) (Table 6.15) although this is not significant. There no effect of Group, $F(1,19) = 0.733$, $MSE = 25257.98$, $p = .403$, no effect of Time, $F(1,19) = 0.309$, $MSE = 4594.04$, $p = .59$, and no significant interaction of these two factors, $F(1,19) = 0.837$, $MSE = 12439.73$, $p = .372$.

	Control Sub-Group (Completed 16 +7 Gz Peaks) (n = 10)		ACP Sub-Group (Completed 16 +7 Gz Peaks) (n = 11)	
	Pre	Post	Pre	Post
30% Max Leg Push Time to Failure (s)				
Pre Centrifuge Runs	492.68 ± 90.47	426.37 ± 67.71	322.58 ± 86.26	297.77 ± 64.56
Post SACMs	269.27 ± 53.53	213.87 ± 45.45	185.71 ± 51.04	199.23 ± 43.34

Table 6.15 Time to failure for 30% of maximum leg push (s) for the Control (n = 10) and ACP (n = 11) sub-groups who completed 16 +7 Gz peaks pre and post intervention. Values are mean ± SE.

6.3.5 *Resting Measurements Pre and Post Intervention*

All physiological measures taken prior to commencing the centrifuge runs with the subjects at rest, were repeated 12 weeks apart and will be described in this section.

6.3.5.1 *Heart Rate*

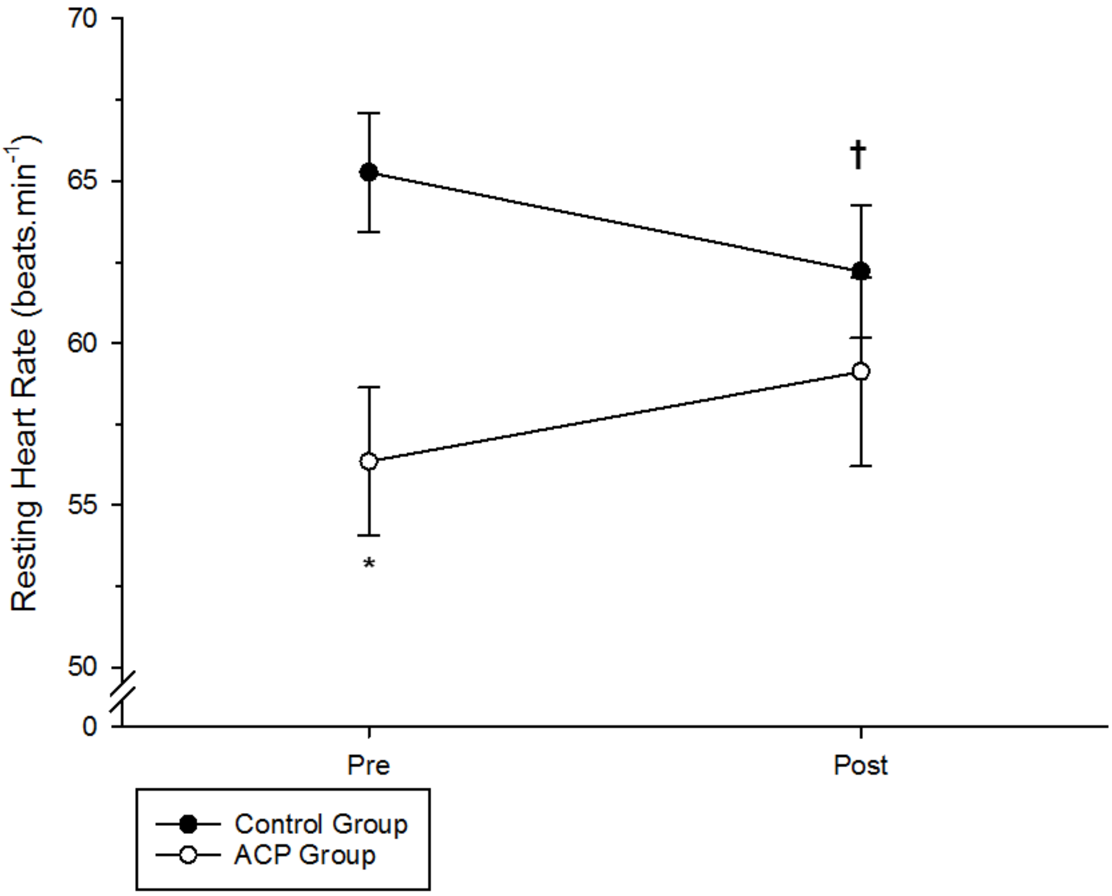

Figure 6.31 Resting HR for Control (n = 19) and ACP (n = 16) group pre and post the intervention. Values are group mean ± SE. *The ACP group had a significantly lower resting HR at baseline (p = .004). †There was a significant interaction between Time and Group (F(1,34) = 8.407, MSE = 151.82, p = .007).

The resting HR for the ACP group was unchanged (pre: 56.4 ± 2.3, *vs* post: 59.1 ± 2.9 beats.min^{-1}) but HR for the Control group reduced significantly (pre: 65.3 ± 1.8, *vs* post: 62.2 ± 2.0 beats.min^{-1}); t(34) = 3.070, p = .004. There was also a significant interaction in resting HR on re-testing between the ACP group and the Control group. There was no effect of Group, $F(1,34) = 3.873$, $MSE = 646.33$, $p = .057$, or Time, $F(1,34) = .021$, $MSE = .37$, $p = .887$, but there was a significant interaction of these two factors, $F(1,34) = 8.407$, $MSE = 151.82$, $p = .007$, with the Control group resting HR reducing significantly ($p = .034$) (Figure 6.31).

6.3.5.2 *Blood Pressure*

There was no significant difference in resting MAP for the ACP group (82.4 ± 1.5 mmHg) or Control group (85.6 ± 1.7 mmHg); $t(34) = 1.448$, $p = .157$. There was also no significant reduction in resting mean SBP and mean DBP for the ACP group on re-testing (Table 6.16). For mean SBP there was no effect of Group, $F(1,34) = 1.00$, $MSE = 202.48$, $p = .324$, or Time, $F(1,34) = 0.001$, $MSE = 0.02$, $p = .979$. The interaction of these two factors was not significant, $F(1,34) = 0.236$, $MSE = 5.57$, $p = .630$. For mean DBP there was no effect of Group, $F(1,34) = 1.611$, $MSE = 107.48$, $p = .213$, or Time, $F(1,34) = 0.027$, $MSE = 0.51$, $p = .871$. The interaction of these two factors was not significant, $F(1,34) = 0.20$, $MSE = 3.84$, $p = .657$.

	Control Group		ACP Group	
	Pre	Post	Pre	Post
Resting SBP (mmHg)	122.2 ± 2.7	121.7 ± 2.9	118.3 ± 2.3	118.9 ± 1.9
Resting DBP (mmHg)	67.3 ± 1.4	66.6 ± 1.6	64.4 ± 1.7	64.7 ± 1.6

Table 6.16 Resting SBP and DBP (mmHg) for the Control and ACP groups. Values are mean ± SE. There was no significant difference between the groups.

6.3.5.3 *Rest and Post Acceleration O_2 Composition*

Resting $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E(STPD)$ and RER were unchanged for both groups (Table 6.17). The ACP group did have a lower resting $\dot{V}CO_2$ and $\dot{V}_E(STPD)$ but this was not significant and post-hoc testing was not significant. There was no other effect of Group, Time, and the interaction of Group and Time was not significant for any of the other measurements (Table 6.18).

	Control Group		ACP Group	
	Pre	Post	Pre	Post
$\dot{V}O_2$ (ml.min.kg^{-1})	4.2 ± 0.1	4.1 ± 0.1	3.9 ± 0.1	4.1 ± 0.1
$\dot{V}CO_2$ (l.min^{-1})	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0	0.3 ± 0.0
RER	0.9 ± 0.0	0.9 ± 0.0	0.9 ± 0.0	0.9 ± 0.0
$\dot{V}_E(STPD)$ (l.min^{-1})	8.7 ± 0.5	8.8 ± 0.4	7.6 ± 0.5	7.6 ± 0.4

Table 6.17 Resting $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E(STPD)$ and RER for the Control and ACP groups. Values are mean ± SE. There was no significant difference between the groups.

	Effect of Group	Effect of Time	Interaction of Group and Time
$\dot{V}O_2$ (ml.min.kg^{-1})	$F(1,34) = 0.396$, $MSE = 0.14$, $p = .533$	$F(1,34) = 0.468$, $MSE = 0.11$, $p = .498$	$F(1,34) = 1.218$, $MSE = 0.29$, $p = .277$
$\dot{V}CO_2$ (l.min^{-1})	$F(1,34) = 5.011$, $MSE = 0.02$, $p = .032$*	$F(1,34) = 0.168$, $MSE = 0.0001$, $p = .684$	$F(1,34) = 0.129$, $MSE = 0.0001$, $p = .722$
RER	$F(1,34) = 2.004$, $MSE = 0.04$, $p = .166$	$F(1,34) = 0.032$, $MSE = 0.0001$, $p = .859$	$F(1,34) = 0.731$, $MSE = 0.01$, $p = .399$
$\dot{V}_E(STPD)$ (l.min^{-1})	$F(1,34) = 5.064$, $MSE = 23.79$, $p = .031$*	$F(1,34) = 0.12$, $MSE = 0.18$, $p = .731$	$F(1,34) = 0.018$, $MSE = 0.027$, $p = .894$

Table 6.18 Results of 2x2 mixed ANOVA for the effects of Group and Time, and the interaction between Group and Time for resting $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E(STPD)$and RER. *The ACP group had a lower resting $\dot{V}CO_2$ and $\dot{V}_E(STPD)$ but post-hoc test was not significant. There was no other effect of Group, Time, and the interaction of Group and Time was not significant for any of the other measurements.

6.3.5.4 *Blood Lactate*

There was a significant interaction in resting blood lactate on re-testing between the two groups (ACP group pre: 2.26 ± 0.2, *vs* post: 1.57 ± 0.2 mmol.L^{-1} and the Control group pre: 1.76 ± 0.2, *vs* post: 1.93 ± 0.2 mmol.L^{-1}). There was no effect of Group, $F(1,34) = 0.157$, $MSE = 0.10$, $p = .695$, no effect of Time, $F(1,34) = 1.86$, $MSE = 1.22$, $p = .182$, and a significant interaction of these two factors, $F(1,34) = 5.171$, $MSE = 3.38$, $p = .029$, with the ACP group resting blood lactate reducing significantly ($p = .017$) (Figure 6.32).

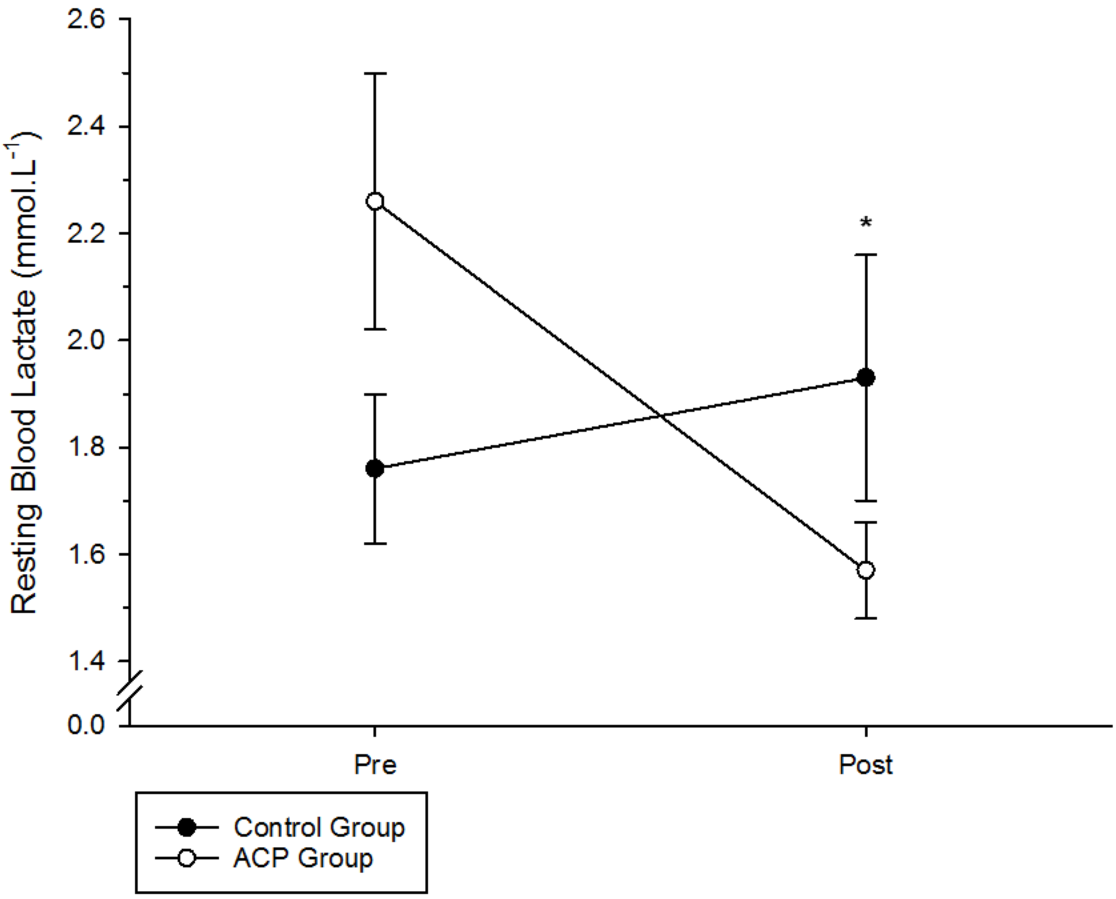

Figure 6.32 Resting blood lactate for Control (n = 19) and ACP (n = 16) group pre and post the intervention. Values are group mean ± SE. *The ACP group had a significantly lower baseline blood lactate on re-testing ($p = .017$).

6.3.5.5 *Leg Muscle Maximum Voluntary Contractions*

Knee flexor force did not record correctly for one of the Control group subjects during initial testing and for one the ACP group on re-testing. The data for these two subjects was excluded from subsequent analysis. There was no significant increase in knee extensor and flexor torque or calf strength for either group on re-testing (Table 6.19).

	Control Group		ACP Group	
	Pre	Post	Pre	Post
Knee Extensor Torque (Nm)	205.7 ± 12.1	210.9 ± 10.6	210.7 ± 13.2	216.5 ± 11.6
Knee Flexor Torque (Nm)	83.2 ± 7.3	83.8 ± 6.2	93.0 ± 8.0	84.7 ± 6.8
Calf Strength (N)	1468.4 ± 79.7	1391.4 ± 73.9	1374.3 ± 86.8	1286.9 ± 80.5

Table 6.19 MVC for knee extensors, knee flexors and calf muscle for the Control and ACP groups. Values are mean ± SE. There was no significant difference between the groups.

For knee extensor torque there was no effect of Group, $F(1,33) = 0.107$, $MSE = 480.45$, $p = .746$, or Time, $F(1,33) = 1.274$, $MSE = 529.07$, $p = .267$. The interaction of these two factors was not significant, $F(1,33) = 0.003$, $MSE = 1.45$, $p = .953$. For knee flexor torque there was no effect of Group, $F(1,31) = 0.306$, $MSE = 463.69$, $p = .584$, or Time, $F(1,31) = 1.698$, $MSE = 240.53$, $p = .202$. The interaction of these two factors was not significant, $F(1,31) = 2.263$, $MSE = 320.67$, $p = .143$. For calf strength there was no effect of Group, $F(1,33) = 0.864$, $MSE = 171308.08$, $p = .36$, but there was an effect of Time, $F(1,33) = 4.487$, $MSE = 117309.90$, $p = .042$. The interaction of these two factors was not significant, $F(1,33) = 0.018$, $MSE = 458.74$, $p = .895$. Calf strength reduced for both groups on re-testing, but post-hoc tests showed no significance at the .05 level of significance.

6.3.5.6 *Foot Pedal Force*

Maximum foot pedal force increased for the ACP group (pre: 4187.4 ± 322.3, *vs* post: 4800.4 ± 311.1 N) and the Control group (pre: 3730.6 ± 295.8, *vs* post: 4232.6 ± 285.4 N). There was no effect of Group, $F(1,33) = 1.779$, $MSE = 4558703.03$, $p = .19$, but there was a significant effect of Time, $F(1,33) = 8.325$, $MSE = 5398543.30$, $p = .007$. The interaction of these two factors was not significant, $F(1,33) = 0.082$, $MSE = 53448.10$, $p = .776$, but post-hoc tests demonstrated showed that the ACP group increased significantly ($p = .002$) (Figure 6.33).

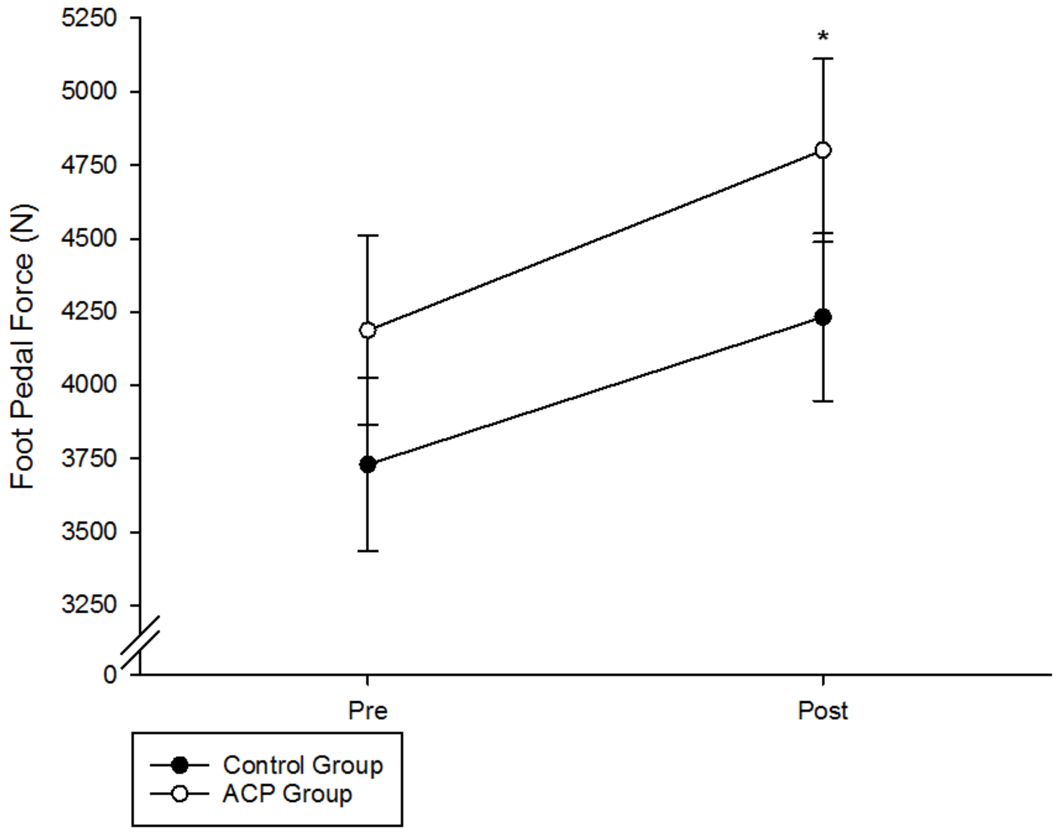

Figure 6.33 Maximum foot pedal force for Control (n = 19) and ACP (n = 16) group pre and post the intervention. Values are group mean ± SE. *The ACP group had a significantly higher maximum foot pedal force on re-testing ($p = .002$).

6.4 Discussion

6.4.1 Overview

The aim of this study was to measure the effect of the ACP, undertaken for 12 weeks on +Gz performance. The performance outcomes were i) relaxed +Gz-level tolerance, ii) straining +Gz-level tolerance during incremental (gradual onset) runs, and iii) +Gz-duration tolerance during a series of SACM profile centrifuge runs. The ACP includes both interval based anaerobic training plus strength training of the lower limb, abdominal and large upper body muscles combined into two sessions per week for 12 weeks. The main findings are summarised in Table 6.20 and will be discussed in greater detail in relation to the effect of ACP on RGT, SGT and on endurance to repeated high sustained +Gz during the SACM runs. Sub-group analysis of those subjects who were able to complete all the SACMs (Table 6.22) and those that could not (Table 6.23), will also be discussed, with the main findings for those groups summarised.

	Control Group (n = 19)		ACP Group (n = 16)		
	Pre	Post	Pre	Post	*p* value
RGT Level (+Gz)	4.6 ± 0.2	4.5 ± 0.2	4.2 ± 0.2	4.4 ± 0.2	*.06*
SGT Level (+Gz)					
HR at +5.5 Gz Step (beats.min^{-1})	148.0 ± 0.0	153.1 ± 3.3	146.0 ± 4.4	↓ 136.9 ± 5.6	.004*
SBP at +5.5 Gz Step (mmHg)	220.6 ± 8.3	↓197.6 ± 7.9	215.1 ± 9.1	224.0 ± 8.7	.007*
SACMs					
Number of +7 Gz Peaks Completed	14.0 ± 1.0	13.6 ± 1.1	13.9 ± 1.2	15.4 ± 0.4	*NS*
Maximum Foot Pedal Force (Nm)	3731 ± 296	4233 ± 285	4187 ± 322	↑ 4800 ± 311	.002*

Table 6.20 Summary of main study findings for Relaxed +Gz Tolerance (RGT), Straining +Gz Tolerance (SGT), Simulated Air Combat Manoeuvre (SACM) centrifuge runs and initial testing. Values are mean ± SE. *There was a significant difference between the groups.

6.4.2 The Effect of ACP on Relaxed +Gz Tolerance

Importantly, the ACP did not negatively affect RGT in this study. Whilst there was a tendency for an interaction of Group and Time (p = .060), with RGT appearing to improve by +0.12 Gz for the ACP group and the Control group reducing by +0.11 Gz, this was not significant. It should also be noted that a change in RGT of +0.1 Gz is not clinically significant, as the day-to-day variation of +Gz tolerance is around +0.38 Gz (Stevenson et al. 2012).

A gradual onset +Gz profile (0.1 $G.s^{-1}$) was used to determine the highest +Gz load the subjects could tolerate whilst remaining relaxed. This rate of acceleration allows the arterial baroreceptor reflex to be fully activated in order to preserve head-level BP and is characterised by an increased HR and peripheral vasoconstriction.

The effect of physical conditioning on the arterial baroreceptor response is inconclusive (Kolegard et al. 2013). Excessive aerobic conditioning is thought to reduce +Gz tolerance (Green 2006, Zhang et al. 1999) as a result of alterations in the balance between sympathetic and parasympathetic activity (Green 2006), characterised by a reduction in resting HR due to increased cardiac vagal activity (Burton 1986), and reduced BP (Cornelissen & Smart 2013). However, a number of studies have demonstrated that aerobic conditioning does not result in a reduced HR response to +Gz (Forster & Whinnery 1990, Kolegard et al. 2013). In the present study there was no significant change in HR response ($\Delta HR.G^{-1}$) during each RGT run.

The ACP group actually demonstrated a tendency for resting HR to increase (p = .066) whilst the Control group significantly reduced (p = .034), and resting MAP was unchanged for both groups. HR response during each RGT run was also unchanged, which, combined with no reduction in RGT, would suggest that the ACP does not adversely affect the arterial baroreceptor response.

Strength training has been advocated to improve +Gz tolerance (Epperson et al. 1985, Tesch et al. 1983), whilst others have failed to conclusively demonstrate any improvement (Bulbulian et al. 1994). Strength training increases arterial stiffness (Otsuki et al. 2007) and individuals with a higher RGT have been shown to have less pronounced pressure-induced distension and flow in leg arteries (Eiken et al. 2012). As part of the baroreceptor response, an increase in peripheral resistance will preserve head-level BP; therefore, strength training may increase RGT. That was not observed in this study and is in agreement with others that strength training does not affect RGT (Kolegard et al. 2013, Bulbulian et al. 1994).

An increase in HR in taller male subjects (194-203 cm) subjected to +2 Gz acceleration on a centrifuge was associated with a larger hydrostatic pressure gradient and greater inhibition of the carotid baroreceptors (Arvedsen et al. 2015). There was no significant difference in subject height between the groups (ACP: 1.81 ± 0.01 m, Control: 1.80 ± 0.01 m) suggesting any changes in HR during +Gz acceleration was not due to hydrostatic pressure gradient or inhibition of the carotid baroreceptors.

6.4.3 The Effect of ACP on Straining +Gz Tolerance

SGT was unchanged for both groups with 6 subjects from the ACP group and 11 from the Control group reaching the +7 Gz plateau on both initial and re-testing. An additional two subjects from the ACP group did reach the +7 Gz plateau on re-testing compared to none in the Control group.

Subjects were instructed to only tense their leg and abdominal muscles sufficiently to maintain clear vision during the stepped profile, resulting in SGT being a measure of the muscle tensing element of the AGSM only. The magnitude of the muscle contraction must be sufficient to increase head-level arterial BP and flow resistance in the vascular beds of the lower body, and decrease pooling of blood in the dependent veins (Kolegard et al. 2013), yet the subject must be able to sustain and increase the muscle contraction with each increase in +Gz acceleration. The contraction of the lower body muscles during the AGSM has been attributed with a major portion of the elevation in BP during rapid onset centrifuge runs up to +5 Gz (MacDougall et al. 1993). Therefore, an increase in lower body muscle strength through weight training may result in less effort being required for a given +Gz level, enabling the individual to achieve a higher SGT. However, there are no studies which have investigated the effects of strength training purely on SGT.

There was marked variation in the point at which all subjects initiated tensing of the lower body muscles but all had commenced some form of tensing by the +5.5 Gz plateau and as a result this plateau was used for subsequent analysis. HR for the ACP group was significantly lower (p = .004) during the +5.5 Gz plateau on re-testing whilst SBP and DBP were unchanged. HR for the Control group was unchanged but SBP was significantly lower (p = .007).

This would suggest that ACP enhances the efficiency of lower body and abdominal tensing with a subsequent reduction in HR whilst maintaining adequate head-level BP at a given +Gz level. An improved cardiovascular tolerance to +Gz exposure is associated with accentuated carotid baroreceptor reflex response, enhanced peripheral vasoconstriction and greater cardiac output (Convertino 1999). A direct correlation between an increase in HR and developing fatigue to repeated high +Gz exposures has been reported (Burton 1980) which would suggest that the significant reduction in HR for the ACP group could indicate a delay in the development of fatigue during the SGT runs.

High sustained +Gz acceleration has a significant impact on improving the function of mechanisms that underlie BP regulation with repeated exposure inducing an increased HR responsiveness in response to arterial baroreceptor stimulation (Convertino 1998).

In G-trained subjects, arterial BP was maintained at a higher level during graded lower body negative pressure (LBNP) compared with controls despite similar HR elevations, a similar response in subjects following G-training (Convertino et al. 1998). During the SGT runs, the ACP group were able to maintain a similar SBP with a lower HR indicating an improved +Gz tolerance exhibited by lower HR at +Gz (Burton 1980).

There is evidence to suggest that endurance training, dynamic resistance training and combined training could reduce DBP and all except combined training could reduce SBP (Cornelissen & Smart 2013). Isometric exercise training may be more effective at lowering BP when compared with dynamic aerobic or resistance exercise training (Millar et al. 2014). Multiple adaptions which include improvements in conduit and resistance vessel endothelium-dependent dilation, oxidative stress, and autonomic regulation of HR and BP are thought to be responsible for lowering resting BP (Millar et al. 2014). The ACP group demonstrated no reduction in SBP or DBP both at rest or during the SGT runs, further suggesting that the ACP is not deleterious to BP and +Gz tolerance.

6.4.4 Does the ACP Effect those with a high SGT?

Sub-group analysis of the 6 ACP and 11 Control group subjects who reached the +7 Gz plateau on both initial and re-testing of SGT was performed to investigate whether the ACP had an effect on those who could already withstand high +Gz loads. Many aircrew have the perception that if they can tolerate a relatively high +Gz level (such as +7 Gz) there is no requirement to participate in a specific conditioning programme such as the ACP. For this reason, sub-group analysis of those subjects who reached the +7 Gz plateau was undertaken. Whilst there was no significant difference for the +7 Gz plateau, there was a significant reduction in HR of 11 beats.min^{-1} (p = .045) for the ACP sub-group only at the +5.5 Gz plateau. HR during the +3.0 Gz plateau was unchanged but this is likely due to the subjects not needing to strain at this +Gz level. There was no significant reduction in MAP for this group during the +7 Gz, +5.5 Gz or +3.0 Gz plateaus (Table 6.21). These results would suggest that the ACP has a positive effect on reducing HR at +5.5 Gz without compromising MAP, even for those individuals who have a SGT of +7 Gz.

	Control Sub-Group (n = 11)		ACP Sub-Group (n = 6)		
	Pre	Post	Pre	Post	*p* value
SGT Level (+Gz)					
HR at +3.0 Gz Step (beats.min^{-1})	125.0 ± 2.2	123.3 ± 3.4	107.6 ± 7.4	104.2 ± 8.4	*NS*
HR at +5.5 Gz Step (beats.min^{-1})	148.8 ± 4.6	154.8 ± 4.1	136.5 ± 9.1	↓125.5 ± 10.8	*.045**
HR at +7.0 Gz Step (beats.min^{-1})	176.4 ± 4.7	175.7 ± 3.7	161.6 ± 9.3	153.5 ± 6.3	*NS*
MAP at +3.0 Gz Step (mmHg)	128.0 ± 3.7	124.1 ± 7.2	123.5 ± 7.3	113.2 ± 9.0	*NS*
MAP at +5.5 Gz Step (mmHg)	155.5 ± 4.0	154.8 ± 9.8	163.7 ± 11.8	146.5 ± 10.1	*NS*
MAP at +7.0 Gz Step (mmHg)	182.4 ± 8.1	175.0 ± 7.4	177.4 ± 16.8	171.4 ± 9.6	*NS*

Table 6.21 Summary of findings for sub-group subjects with a high straining +Gz-level (SGT) tolerance. Values are mean ± SE. *There was a significant difference between the groups.

6.4.5 The Effect of ACP on Endurance to Repeated High Sustained +Gz

The number of +7 Gz peaks completed by the subjects in the ACP group during the SACM runs improved, except for one subject who stopped due to nausea, however this was not significant. The performance of the entire ACP group during the SACMs, which consisted of 16 +7 Gz peaks, will be discussed initially followed by sub-group discussion of the subjects in both groups (11 in the ACP group and 10 in the Control group) who completed all 4 SACMs pre and post intervention. These latter subjects are those who would be described as having a high +Gz duration tolerance whereas those subjects who were unable to complete all 16 +7 Gz peaks on initial testing (ACP group n = 4; Control group n = 5) would be described as having a low +Gz duration tolerance.

There are a number of possible reasons why the ACP group improved the number of +7 Gz peaks completed on re-testing. Cardiovascular tolerance of orthostatic stress can be improved with frequent high sustained +Gz exposure (Stevenson et al. 2014, Scott et al. 2013, Convertino 1999). Two (8 SACMs) or 4 sessions (16 SACMs) of SACMs per week for 3 weeks have been found to enhance cardiovascular tolerance but not improve RGT (Scott et al. 2013). Subjects in this study completed a maximum of 4 SACMs in a single session with a minimum of 12 weeks between repeating, which is unlikely to be sufficient +Gz exposure to improve cardiovascular tolerance.

The ability to tolerate the SACM runs required the subjects to perform a full AGSM which includes isometric contractions of the lower limb and abdominal muscles plus repeated brief VMs. Frequent exposure to SACMs provides subjects with increased familiarity and experience of performing the AGSM, providing practice (Scott et al. 2013) of a highly complex, unnatural, athletic psychomotor skill (Bateman et al. 2006). Undoubtedly, AGSM practice would be expected to increase +Gz tolerance, but both groups had the same training and time on the centrifuge, and neither reported participation in high +Gz sorties (ACM/BFM flying) in the weekly activity logs. The Control group did not increase the number of +7 Gz peaks completed during the SACM runs.

RPE is a psycho-physical tool used to assess subjective perception of effort during exercise (Scherr et al. 2013) and is closely related to blood lactate concentrations and HR intensity parameters (Borg et al. 1985, Scherr et al. 2013). RPE for each SACM increased with the highest score being reported for SACM 4 for both groups indicating the progressive fatigue. Cumulative RPE was similar for both groups pre and post intervention, and significantly reduced for both groups which would suggest that practice of the AGSM is a factor.

Blood lactate levels are highest at 3 min post SACM (Wiegman et al. 1995, Tamir et al. 1988, Burton et al. 1987) with levels post-SACM being reported in the region 4.2 – 5.2 mmol.L^{-1} (Bain et al. 1992, Wiegman et al. 1995, Burton et al. 1987). This is slightly lower than the levels recorded for both groups in this study (ACP group pre: 5.6 ± 0.5 mmol.L^{-1}, *vs* post: 5.9 ± 0.7 mmol.L^{-1}, Control group pre: 6.4 ± 0.5 mmol.L^{-1}, *vs* post: 7.0 ± 0.6 mmol.L^{-1}). This may be due to these subjects being relatively inexperienced in performing the AGSM as the SACM profiles (+5 to +7 Gz) were similar to the other studies.

Peak HR did not reduce for the ACP group during each successive SACM although it should be noted that the number of subjects completing each SACM progressively reduced. In the ACP group peak HR was recorded for 16 subjects during SACM 1 but this dropped to 12 subjects by SACM 4 (Control group: SACM 1 = 19, SACM 4 = 14).

Peak HR progressively increased with each SACM for both groups, similar to previous studies (Burton 1980, Burton et al. 1987) which would indicate developing fatigue. Unfortunately, due to technical limitations, reliable measurements of BP were not possible during the +7 Gz peaks, preventing a comparison of BP with peak HR.

During the SACMs the AGT were able to inflate, whereas they were not for the RGT and SGT runs. Whilst it was not possible to accurately record BP during the +7 Gz peaks of the SACMs it has to be assumed that the contribution of the AGT to maintaining BP is constant as the pressure is the same for any given +Gz (MacDougall et al. 1993).

6.4.5.1 *The Effect of ACP on Subjects with a High +Gz Duration Tolerance*

All 4 SACMs were completed pre- and post-intervention by 11 subjects in the ACP group and 10 in the Control group. These subjects are those individuals who have a high +Gz duration tolerance and it could be assumed that they would not benefit from participating in the ACP. However, cumulative RPE for the ACP sub-group significantly reduced (p = .038) (Table 6.22) which would suggest that the ACP enhances +Gz duration tolerance for those subjects who already have a high +Gz duration tolerance through reducing the perceived effort to complete the SACMs and thus fatigue development. Unfortunately, there were no other significant changes for the ACP sub-group compared to the Control sub-group.

	Control Sub-Group (n = 10)		ACP Sub-Group (n = 11)		
	Pre	Post	Pre	Post	*p* value
SACMS	16	16	16	16	
RPE	27.2 ± 1.2	25.4 ± 0.9	28.6 ± 1.2	↓ 26.6 ± 0.9	*.038**

Table 6.22 Summary of findings for sub-group subjects with a high +Gz duration tolerance. Values are mean ± SE. *There was a significant difference between the groups.

6.4.5.2 *The Effect of ACP on Subjects with a Low +Gz Duration Tolerance*

Three out of the 4 subjects in the ACP low +Gz duration tolerance group managed to complete all 16 +7 Gz peaks on re-testing, with 3 from the Control group improving (Table 6.23). The subjects with a low +Gz duration tolerance represent the largest flight safety risk due to the risk of experiencing G-LOC or A-LOC and may benefit most from the ACP if it can increase the number of +7 Gz peaks completed. Unfortunately, the low number of subjects precluded any meaningful statistical analysis but further study of this group with a larger sample size should be considered for future research.

	Control Sub-Group (n = 5)		ACP Sub-Group (n = 4)	
	Pre	Post	Pre	Post
SACMs				
Number of +7 Gz Peaks Completed	8.4 ± 2.2	10.4 ± 3.4	7.8 ± 3.6	14.8 ± 1.3
RPE	33.8 ± 3.2	31.3 ± 2.8	36.0 ± 3.2	32.5 ± 2.8

Table 6.23 Summary of findings for the sub-group subjects with a low +Gz duration tolerance. Values are mean ± SE.

6.4.6 *Limitations*

As previously discussed the AGSM is a hugely varied and complex skill and this is evidenced by the individual variability in EMG activity of the leg muscles. Coupled with the inability to accurately record BP during the +7 Gz peaks, SACM centrifuge profiles proved highly challenging for recording complete data sets. SACM profiles remain popular in +Gz acceleration research due to the ability to replicate the +Gz onset and duration rate experienced by fast-jet aircrew in a consistent manner, however, a more controlled centrifuge profile may be more appropriate. The stepped profile used in this study was designed to measure +Gz-duration tolerance when using only the lower body and abdominal muscle contraction element of the AGSM. As this element can provide up to +4 Gz protection if performed correctly (Chen et al. 2004) it was felt that this profile would provide the greatest insight into whether the ACP can improve +Gz tolerance. Whilst this profile can provide a controlled environment to enable accurate measurement of physiological parameters, it is not indicative of the +Gz profiles used with modern fast-jet aircraft which have a greater +G onset rate.

Adherence to the ACP was monitored through the weekly activity logs due to the split location of the two groups, with the integrity and accuracy of the subjects relied upon. Subjects were provided with a contact telephone number and received regular email correspondence to monitor progress in an effort to achieve maximum adherence.

Only males were used as subjects for this study despite efforts to recruit female aircrew. Unfortunately, there were no females within the RAF or RN flying training (FT) pipeline during the 18 month period of the study. Future studies should repeat the research with female aircrew in order to allow comparison with the results of this study.

There was a significant difference in age between the two groups which can be explained by the nature of the UK military FT pipeline. All student aircrew undertake EFT with those selected to become fast-jet aircrew going on to BFJT. This process takes 1-2 years and is the reason for the difference in age. It should be noted that the mean age difference of 2 years was unlikely to influence the results in the young adult cohort. Whilst the ACP group were recruited from BFJT students and as such had more flying hours than the Control group recruited from EFT students, all the flying undertaken was of a low +Gz profile with minimal requirement / practice of the AGSM. In an effort to limit the effect of AGSM practice, the Control group completed the same training as the ACP group on the centrifuge, with identical coaching on the AGSM prior to the start of data collection.

6.4.7 Conclusions

The ACP performed for 12 weeks did not negatively affect relaxed and straining +Gz-level tolerance, and appeared to enhance +Gz-duration tolerance to repeated high sustained +Gz during a series of SACM profile centrifuge runs particularly for subjects with low +Gz-duration tolerance. The ACP may also be effective in enhancing aircrew performance in a controlled high +Gz environment by reducing physiological strain at given levels of +Gz.

Chapter 7 General Discussion and Conclusions

7.1 Overview

The overarching aim of this thesis was to further understand the present status of +Gz related incidents in the RAF, and design, construct validate and test the efficacy of a physical conditioning programme (ACP) on performance under high +Gz. The prevalence of G-LOC and A-LOC in the RAF (Chapter 4) was determined. An exercise programme (ACP) was designed and underwent construct validity by a panel of experts for appropriateness for delivery to an aircrew population by a team of trained PTIs and physiotherapists (Chapter 5). The efficacy of the ACP to have a beneficial effect on aircrew performance in a controlled high +Gz environment was then investigated (Chapter 6). In the following section (7.2) the main findings from each chapter of this thesis are summarised. An overview of the major contributions of this work will be discussed (section 7.3). Finally, after a review of the methodological limitations of the studies (section 7.4), avenues for future research are considered (section 7.5).

7.2 Summary of Primary Findings

7.2.1 Incidence of G-Induced Loss of Consciousness and Almost Loss of Consciousness in the Royal Air Force

The prevalence of reported G-LOC in the RAF has decreased to 14.8% since the previous survey in 2005 (20.1%). A-LOC was reported by 32.2% of respondents although it should be noted that the 2005 survey did not ask aircrew about any possible A-LOC experiences (Green & Ford 2006). G-LOC and A-LOC remain a hazard to all aircrew, particularly those flying the predominant trainer aircraft (Hawk, Tucano, Grob Tutor) which accounted for 65.4% of G-LOC and 71.3% of A-LOC events (Table 4.1).

This has reduced slightly from the 77.4% of G-LOC events reported in 2005 and may result from the introduction of centrifuge-based training for all fast jet aircrew prior to the Tucano flying phase. However, of concern is the number of aircrew who have reported a +Gz event during the initial stages of flying training on the Grob Tutor (5 G-LOC and 19 A-LOC events) as none were reported in 2005. Student aircrew reported a higher incidence of both +Gz events, presumably due to their relative inexperience in both Gz awareness and ability to perform an effective AGSM.

Currently all RAF aircrew commence their flying training on the Grob Tutor aircraft and as such have minimal flying experience. As part of their training, they receive classroom-based Gz theory lectures and basic AGSM instruction. Measures to significantly reduce the incidence of these events in this group could include more formalised Gz theory classroom lectures and correct execution of the AGSM and centrifuge training earlier than currently undertaken. Interestingly, only 33% of respondents had participated in centrifuge training, with the others having undergone flying training before this policy was introduced, and of the 105 who did report a G-LOC event, 55.2% had not completed centrifuge training. Unfortunately, due to the structure of the survey, it is unclear whether those who did report a G-LOC event had completed centrifuge training prior to the event.

Awareness of the basic prevention measures of G-LOC and A-LOC were high in respondents with the perceived importance of centrifuge training increasing the most (72.8% in 2012 compared with 55.6% in 2005). A total of 524 aircrew felt that centrifuge training was of value, with 330 (62.9%) having not experienced a G-LOC or A-LOC event ($p < .048$). The importance of physical conditioning was also perceived as important (‘very’ or ‘fairly’) by 84.7% of respondents (82.7% in 2005), with the majority of respondents participating in regular (2 – 3 sessions per week) aerobic conditioning (60.7% of 624 respondents). Fewer respondents participated in regular anaerobic (42.5% of 471 respondents) or strength based (43.9% of 490 respondents) sessions.

7.2.2 Content Validity of the Aircrew Conditioning Programme

The ACP was designed to enhance aircrew performance through improvements in the ability to repeatedly perform an effective AGSM and reduce strain injuries to the neck, enhancing the ability to look out of the cockpit. It underwent content validation by a panel of experts for appropriateness for delivery to an aircrew population by a team of trained PTIs and physiotherapists.

The ACP demonstrated excellent content validity for the individual exercise sessions (I-CVI) and for the overall programme (protocol-CVI) in terms of relevance and simplicity for delivery to the aircrew population. Of the 24 exercise sessions, 20 were rated excellent (I-CVI 1.00) for relevance and 21 were rated excellent (I-CVI 1.00) for simplicity. The remaining exercise sessions were rated acceptable (I-CVI 0.83) for relevance and simplicity. S-CVI/Ave reached 0.97 for relevance and 0.98 for simplicity, which was higher than the recommended 0.90 (Polit & Beck 2006).

Sufficient supervision of the aircrew during the exercises was recommended by the panel of experts to ensure safe execution of the exercises and to maintain aircrew adherence to the ACP. Whilst it is comprehensive in its detail, all the exercises are relevant to the population and the demanding environment they work in.

7.2.3 The Effects of the Aircrew Conditioning Programme on Physiological Performance in a High +Gz Environment

In a controlled high +Gz environment, the ACP did not negatively affect RGT or SGT. However, during the +5.5 Gz SGT step a lower physiological strain was indicated in the ACP group by a lower HR (10 beats.min^{-1}) for the equivalent load (pre 146.0 ± 4.4, vs post 136.9 ± 5.6 beats.min^{-1}) compared to the Control group (pre 148.0 ± 3.2, vs post 153.1 ± 3.3 beats.min^{-1}) (p = .004), while mean arterial blood pressure (MAP) was unchanged. For the ACP sub-group subjects who had a high straining +Gz-level tolerance (able to reach the +7 Gz plateau), HR at the +5.5 Gz step was 11 beats.min^{-1} lower (p = .045) without compromising MAP.

During the SACM runs the number of +7 Gz peaks completed per subject (maximum of 16) had a tendency to increase in the ACP group only (pre 14.0 ± 1.2, post 15.4 ± 0.4 peaks per subject) whereas the control group had a tendency to reduce (pre 14.0 ± 0.9, post 13.6 ± 1.1 peaks per subject). Cumulative RPE significantly reduced for both groups indicating practice of the AGSM is a factor in improving +Gz-duration tolerance.

A sub-group of subjects in the ACP group who had a high +Gz duration tolerance, indicated through completion of all 16 +7 Gz peaks pre- and post-, had significantly lower cumulative RPE (p = .041) suggesting that the ACP enhances performance in this group through reducing perceived effort and thus fatigue development. For the subjects who had a low +Gz duration tolerance, all increased the number of +7 Gz peaks, with the greatest improvements occurring with the ACP sub-group. Unfortunately, the small numbers precluded meaningful statistical analysis, although it could be inferred that this group also benefits from the ACP in terms of a reduction in perceived effort during the SACMs.

7.3 Implication of Findings and Recommendations

As a result of the findings of the survey in Chapter 4, measures to significantly reduce the incidence of these events in this group have been taken by the RAF, which includes more formalised Gz theory classroom lectures and more formal practice of a correct AGSM technique as part of centrifuge training is now undertaken earlier for those aircrew selected to fly fast-jet aircraft. Further research is planned to investigate the effect of the ACP on reducing strain injuries to the neck.

To the author's knowledge the study described in Chapter 6 is the first to demonstrate a reduction in physiological load under relatively high +Gz (+5.5 Gz) following participation in a physical conditioning programme. The ACP has now been adopted across the RAF, RN and Army as the recommended physical conditioning programme to enhance aircrew performance. There are now plans to refine the ACP to enhance performance in rotary aircrew, both front and rearcrew, and further enhance performance in fast jet aircrew.

7.4 Strengths and Limitations of Research

The relatively low response rate of 34% for the G-LOC survey (Chapter 4) could be improved through providing a verbal brief to aircrew prior to distribution of the survey. The brief should explain the purpose, and signs and symptoms of both G-LOC and A-LOC which may encourage a greater response rate. Future surveys should also include more detail of centrifuge training and whether aircrew felt this training enhanced their ability to recognise G-LOC or A-LOC symptoms.

Following content validation (Chapter 5) a number of additional exercises were included in the ACP, and additional supervision in the form of an extra PTI to aide delivery of the more complex and technically challenging exercise sessions.

The centrifuge study described in Chapter 6 encompassed use of the only UK man-rated centrifuge, which was limited in maximum onset rate due to its performance and age. Whilst the centrifuge provides a controlled high +Gz environment it is unable to replicate the onset rates of current RAF aircraft. The relatively small subject numbers may have reduced the power to detect small effects. Unfortunately, the ethical requirement to recruit medically fit subjects who were also aircrew limited the numbers used.

7.5 Future Considerations

The RAF has plans for a new human centrifuge in operation in the next year with an onset rate in line with current operational aircraft. Elements of this study would benefit from being repeated on the new centrifuge to allow comparison of results and investigation of respiratory fatigue during the AGSM. Further work involving the new centrifuge could also develop a mechanism of identifying those aircrew who had a poor +Gz duration tolerance and posed the greatest flight safety risk.

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Chapter 9 Appendices

Appendix 1 G-LOC and A-LOC Survey

Appendix 2 ACP Level 2 Aircrew Aide Memoire

Appendix 3 MODREC Approval Letter

Appendix 4 Participant Information Sheet

Appendix 5 Health Screen for Study Volunteers

Appendix 6 Weekly Activity Log (1 Week Only Shown)

Royal Air Force Centre of Aviation Medicine
Aviation Medicine Wing

INVESTIGATION INTO THE INCIDENCE OF G-INDUCED LOSS OF CONSCIOUSNESS (G-LOC) IN THE RAF - 2012

Notes on completing this questionnaire
Please answer only about your experience whilst flying for the RAF and fill one circle per question or sub-question only. Please use a pencil to fill in the circles; you can use any grade of pencil. If you make a mistake simply rub out your mark and mark another option. Completely fill circles with your pencil mark.

Demographics

1. What is your age as at 31st December 2012?

Under 24 O

25-29 O

30-34 O

35-39 O

40-44 O

45-49 O

50-55 O

Over 55 O

2. What is your current aircraft role?

Fast Jet O

Transport/Multi-engine O

Rotary O

Light Aircraft Trainer O

Ground Tour O

ISTAR O

Test Flying O

Other (specify) O

3. What is your role?

Pilot O

Weapons System Operator O

Other (specify) O

Almost Loss of Consciousness

Sign / Symptom[1]	Description
Poor response to auditory stimuli	Hearing a radio call or noticing an alarm and not knowing why or what to do about it
Abnormal sensation in limbs	Twitching, tingling, weakness or paralysis
Lack of recall	Difficulty remembering how to perform routine tasks
Confusion	Unsure what you are doing or why you are doing it
Dream-like state	Feeling like you are somewhere else, doing something else
Euphoria	Warm, fuzzy feeling that everything is wonderful
Apathy	Not caring about what is going on around you
Displacement / disorientation	Not knowing where you are
Loss of short term memory	Unable to recall recent event

4a. The table above describes the signs and symptoms of 'Almost Loss of Consciousness' (A-LOC). Have you ever suffered some or all of these symptoms whilst pulling G?

Yes O

No O

4b. If YES, how many times in your flying career?

1 O

2 O

3 or more O

4c. If YES, was it:

Solo O How many? [ ]

Dual O How many? [ ]

G-Induced Loss of Consciousness

5a. Have you ever lost consciousness in flight while pulling G?

Yes O

No O

5b. If YES, how many times in your flying career?

1 O

2 O

3 or more O

5c. If YES, was it:

Solo O

Dual O

If you answered YES to Q4a or Q5a, please complete questions 6 to 17 for the <u>most significant</u> incident then complete the remainder of the form.

If you answered NO to Q4a <u>and</u> Q5a, please go to question 18.

Incident Details

6. In the following section, you will be asked to describe one incident; is this incident related to:

G-LOC O

A-LOC O

[1] From Rickards A, Newman G. G-Induced Visual and Cognitive Disturbances in a Survey of 65 Operational Fighter Pilots. *Aviat, Space and Environ Med* 2005; 76: 496-500.

7. Give the approximate date of the incident:

Before 1980	O
1981 - 85	O
1986 - 90	O
1991 - 95	O
1996 - 2000	O
2001 - 2005	O
2006 - 2010	O
2011 to date	O

8. What was the aircraft type?

Bulldog	O
Canberra	O
Firefly	O
Grob Tutor	O
Harrier	O
Hawk	O
Hunter	O
Jaguar	O
Jet Provost	O
Phantom	O
Tornado GR1/GR4	O
Tornado F3	O
Tucano	O
Typhoon	O
Other (specify)	O

9. What was your level of experience at the time?

EFTS	O
BFTS	O
Fast Jet Conversion	O
OCU	O
Sqn	O
Instructor	O
TP	O
Other (specify)	O

10. What was your flying experience at that time?

a. Approximate hours on type:

0 - 99	O
100 - 249	O
250 - 499	O
500 - 999	O
1000 - 1999	O
2000 - 2999	O
Above 3000	O

b. Approximate hours total:

0 - 99	O
100 - 249	O
250 - 499	O
500 - 999	O
1000 - 1999	O
2000 - 2999	O
Above 3000	O

11. Were you controlling the aircraft at the time?

Controlling	O
Not Controlling	O

12. What was the maximum G pulled?

3.0 - 3.9	O
4.0 - 4.9	O
5.0 - 5.9	O
6.0 - 6.9	O
7.0 - 7.9	O
8.0 - 8.9	O
9 or above	O
Don’t know	O

13. Was the G onset rate:

Rapid O

Slow O

14. Was the aircraft 'unloaded' to less than 1G immediately before the manoeuvre that caused G-LOC / A-LOC?

Yes O

No O

15. Were you straining?

Yes O

No O

16. Were you wearing a functioning anti-G suit?

Yes O

No O

17. Please list any other factors that you think might have contributed to the G-LOC / A-LOC?

18. How important do you consider each of the following in reducing the incidences of G-LOC?

	Not at all	**Not very**	**Fairly**	**Very**
Flying Currency	O	O	O	O
Centrifuge Trg	O	O	O	O
Conditioning Trg	O	O	O	O
Anti-G Suit	O	O	O	O
G-theory Lectures	O	O	O	O

19. Have you participated in any of the following?

	Not at all	**Not very**	**Fairly**	**Very**
Centrifuge Trg	O	O	O	O
Regular aerobic Conditioning	O	O	O	O
Regular anaerobic Conditioning	O	O	O	O
Regular strength Training	O	O	O	O

20. Please add any further comments you may have about your experiences of G-LOC or A-LOC

Thank you for your cooperation in completing this form. Please **return it using the enclosed envelope** to: RAF Centre of Aviation Medicine, RAF Henlow, Bedfordshire, SG16 6DN. If you require any further information regarding the completion of this form please contact Flt Lt Ellen Slungaard (95381 Ext 6460) Research Physiotherapist at RAF CAM, RAF Henlow.

RAF Centre of Aviation Medicine
2015 Issue

AIRCREW CONDITIONING PROGRAMME

AIRCREW AIDE-MEMOIRE

NAME____

INSTRUCTIONS FOR USE

1. This Aide-Memoire is designed for aircrew who have participated in supervised Aircrew Conditioning Programme (ACP) sessions.

2. Please bring this document to every supervised ACP session in order to allow the Station Physiotherapist and/or ACP Instructor Course (ACPIC) qualified PTI to update sections as required.

3. It contains sample exercise sessions for all the elements of the ACP. As you progress through your flying training the sessions are designed to become more difficult and specific to your airframe. These will be added to this Aide Memoire on completion of the supervised ACP sessions.

4. You should aim to complete at least one session of neck strengthening exercise and either one session of strengthening or cardiovascular exercise each week.

5. If at any point you feel untoward discomfort during or after the exercise session please contact your Station Physiotherapist.

CURRENT LEVEL OF PROFICIENCY:

(To be completed by Stn ACP lead in pencil)

Neck Strengthening – 1 / 2 / 3 / 4

Strength Training – 1 / 2 / 3 / 4

Core Stability – 1 / 2 / 3 / 4

Date: ………………………… Station: ……………………………………

Assessor Signature: ………………………………………………...............

ACP SCORING

ACP Pathway

	Level 1	Level 2	Level 3	Level 4	Review	Review
Neck Strength						
Lifting Technique						
Core Stability						
Anaerobic Training						

ACP Measurements

	Date of Test							
Grip	**R (best of 3)**							
	L (best of 3)							
Neck	**Occipital to C7 -**	**Circumference**						
Neck ROM (°)	**Flexion**							
	R Rotation							
	R Lateral Flexion							
	Extension							
	L Lateral Flexion							
	L Rotation							
Neck Strength (kg)	**Flexion**							
	R Anterio-lateral Flexion							
	R Lateral Flexion							
	R Posterio-Lateral Flexion							
	Extension							
	L Posterio-Lateral Flexion							
	L Lateral Flexion							
	L Anterio-Lateral Flexion							
RAST								
FMS								

CONTENTS

WHAT IS THE AIRCREW CONDITIONING PROGRAMME?

The Aircrew Conditioning Programme (ACP) is designed to enhance pilot performance through reducing fatigue and strain injuries, specifically to the neck. It incorporates well established exercise and conditioning techniques from both other military air forces and the sports medicine community, utilising measurable outcomes at both commencement and completion of the programme.

The requirement for the ACP has been endorsed by DFT, DComd JHC and HQ 1 Gp1 (Annex C to AP3342 Section 4 Leaflet 407).

The prevalence of flight-related neck pain in all RAF aircrew is 66% (Wickes and Greeves, 2006). Physical conditioning programmes have been effective in reducing the prevalence of flight-related neck pain reported by aircrew (Ang and Harms-Ringdahl, 2006). Rotary wing aircrew who perform regular aerobic exercises, weight training and neck strengthening have a lower incidence of neck pain (Ang and Harms-Ringdahl, 2006). Low level muscle control of neck and core muscles, with strength and endurance training of the large muscle groups is recommended for both fast jet (Bateman et al., 2006) and rotary wing aircrew (Salmon et al., 2011).

The ACP consists of four main elements;

- Whole body flexibility and mobility involves exercises in specific movement patterns that require a balance of mobility and stability.
- Cardiovascular fitness focusing on anaerobic capacity, with sessions involving a combination of weighted whole body exercises and high intensity cardiovascular exercises.
- Stabilisation and motor control exercises for both the neck and lower back. The main aims are to maintain cervical spine (neck) neutral in all positions and develop rotational core control in a seated position.
- Strengthening of the neck, back, abdominal and leg muscles incorporating isometric neck loading in neutral, upper quadrant and Olympic type lifting techniques.

The main aims are to maintain cervical spine neutral under load, reduce compensation strategies during loading and strengthen the muscles involved in the anti-G straining manoeuvre (AGSM).

Fast Jet ACP Pathway

ACP Level	Flying Training	ACP Exposure	Minimum Standards to Progress
1	EFT	Minimal	**Neck Strengthening** – Can activate deep neck flexors, Level 1 Theraband competent **Strength Training** – Initial technique instruction **Core Strengthening** – Neutral posture in all positions
2	BFJT	Competent Level 1	**Neck Strengthening** – Level 2A & B head harness competent **Strength Training** – Consolidation of lifting technique **Core Strengthening** – Static rotational control in all positions
3	AFJT / AJT / TW	Competent Level 2	**Neck Strengthening** – Level 3A & B head harness competent **Strength Training** – Progression of weight maintaining technique **Core Strengthening** – Dynamic rotational control on a stable base
4	OCU / Frontline Sqn	Competent Level 3	**Neck Strengthening** – Level 4A & B head harness competent **Strength Training** – Further progression of weight **Core Strengthening** – Dynamic rotational control on an unstable base

Rotary ACP Pathway

ACP Level	Flying Training	ACP Exposure	Minimum Standards to Progress
1	EFT	Minimal	**Neck Strengthening** – Can activate deep neck flexors, Level 1 Theraband competent **Strength Training** – Initial technique instruction **Core Strengthening** – Neutral posture in all positions
2	SERW MERW	Competent Level 1	**Neck Strengthening** – Level 2A & B head harness competent **Strength Training** – Consolidation of lifting technique **Core Strengthening** – Static rotational control in all positions
3	OCU AAC	Competent Level 2	**Neck Strengthening** – Level 3A & B head harness competent **Strength Training** – Progression of weight maintaining technique **Core Strengthening** – Dynamic rotational control on a stable base
4	Frontline Sqn	Competent Level 3	**Neck Strengthening** – Level 4A & B head harness competent **Strength Training** – Further progression of weight **Core Strengthening** – Dynamic rotational control on an unstable base

Pre Flight Warm Up

Dynamic Neck Stretches

- **Slow controlled** movements through the **full range** of motion.

- Should be appropriate to the movements you would experience during your sortie.

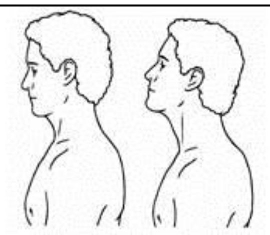
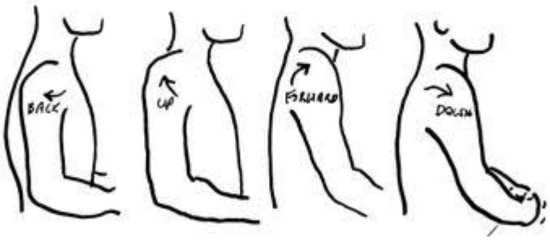
- **Not forcing** your body to extend its range of motion.

- Reduces the risk of injury and **fires up your muscles** for peak performance.

- The flexibility gained by dynamic stretching is due to a slight **rise in muscle temperature** allowing stimulation of the nervous system and elongation of muscles.

Referenced from Hardwick (2002)

Perform these exercises prior to getting into the aircraft, and again when in the aircraft with helmet on.

	**Flexion / Extension** Tuck your chin in and slowly look to the floor and the ceiling as far as you can. Return to neutral alignment **Repeat 5 times**
	**Lateral Flexion** Looking forward, slowly lower your ear toward your shoulder, return to neutral alignment and then repeat to the other side **Repeat 5 times**
	**Rotation** Keeping chin tucked in, turn to look over your left shoulder and return to neutral alignment, then rotate your head towards your right shoulder **Repeat 5 times**
	**Combined Extension and rotation- 'check 6'** In a slow and controlled manner, look up towards the ceiling and over your right shoulder. Return to neutral alignment and repeat to the left **Repeat 5 times**
	**Protraction / Retraction** Without nodding head forward or backwards, poke the chin as far forward as you can, then tuck it in, making as many double chins as you can **Repeat 5 times**
	**Shoulder circles** Slowly circle shoulders forwards, up to ears, back and down and far as possible in each direction **Repeat 5 times**

Referenced from PhysioTools and Hardwick (2000)

Post Flight Cool Down

Static Neck Stretches

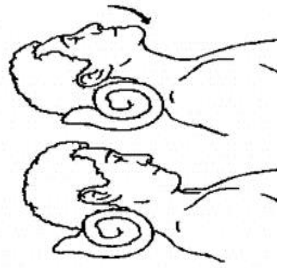
- **To lengthen shortened muscles, fascia, or ligaments**. Prolonged protracted head postures maintain neck extensors in a shortened position (flying postures). This causes permanent shortening of the muscles, fascia and ligaments resulting in dysfunction, premature joint degeneration, headaches, and difficulty achieving normal posture.

- **To relax tense muscles.** The best way to get a muscle to relax is through a slow stretch. Stimulating golgi tendon organs (a nerve receptor found in tendons) through a slow stretch causes reflex inhibition and hence relaxation of the muscle being stretched.

- **To move and lubricate joint surfaces**. Cartilage is lubricated through movement and weight bearing.

Referenced from Chalmers (2004)

Perform these stretches as soon is practical on finishing your sortie.

	**Flexion** Tuck chin to chest and roll head forwards. Use both hands to gently increase the stretch. **Hold for 30 seconds**
	**Side flexion** Hold side of chair or sit on right hand. Bring left ear to shoulder and use left hand to further increase this stretch. **Hold for 30 seconds each side**
	**Rotation** Look over your shoulder as far as possible. Use hand to push at jaw to increase stretch. **Hold for 30 seconds each side**
	**Flexion with rotation** Place right hand behind back or sit on hand. Side flex as far as possible to left before adding left rotation. Use left hand on the top of your head to further increase this stretch **Hold for 30 seconds each side**
	**Upper neck flexion** Place a rolled towel under the base of your head. Keeping your head heavy and relaxed, roll chin to chest, lengthening your neck. You should not be straining to hold it here. You can also perform this stretch in the car with head on head rest whilst driving home. **Hold for 5 minutes**

Referenced from PhysioTools and Chalmers (2004)

Mobility

THEORY

Mobility techniques and programmes are recommended for aircrew personnel (Llewellyn et al., 2010).

Reduced flexibility in one body part can cause excessive loading in another; for example tight hamstrings can cause excessive mechanical stress and develop low back pain (Pelham et al., 2005).

Flexibility regimes are recommended for aircrew to prevent low back pain (Gaydos, 2012).

Improved mobility and flexibility increase the ability to handle and move loads and reduce manual handling injury risks. This is of particular benefit to RW rearcrew (Llewellyn et al., 2010).

Stretching regimes are recommended for aircrew personnel to prevent flight related dysfunction (Pelham et al., 2005).

Mobility

GENERAL STRETCHING EXERCISE GLOSSARY

Crook Lying Rotations

- Shoulders in contact with the floor
- Rotate and drop knees to the floor
- Movements should be rhythmical
- Gently extend top leg to increase stretch
- Rotate upper body in the opposite in order to take the stretch even further

Scorpion

- Start in prone lying
- Front of your shoulders remain n contact with the floor
- Rotate and drop foot to the floor on the opposite side (as shown)
- Movements must be controlled and rhythmical
- Repeat on the opposite side
- **No pain should be felt during this exercise**

Mobility

Torso Rotation with Lunge

- Start in standing
- Complete a single lunge with trunk rotation
- Keep lower limbs facing forwards
- Repeat on the opposite side

4 Point Rotations

- Start in 4 point kneeling your hands under your shoulders and knees under your hips
- Sweep your arm under and through your body. Keep your static arm straight and aim to get your moving shoulder to the floor
- Rotate back around, open your body out and reach up and around
- Movements should be rhythmical
- Repeat on the opposite side

<u>Don’t forget your arm and leg stretches</u>

Mobility

MOBILITY NOTES:

Mobility

FOAM ROLLING

THEORY:

Fascia is a connective tissue that surrounds your muscles and helps to link structures within your body (Drake et al., 2011). Fascia can become restricted leading to reductions in flexibility and impaired muscle control, strength and endurance (Barnes, 2007). Each of these limitations can lead to pain (Barnes, 2007).

Foam rolling is a technique designed to assist with myofascial release (Sullivan et al., 2013) and has been proven to improve range of movement and flexibility (Sullivan et al., 2013). Its actions are thought to result from the fascia becoming more permeable and less dense which subsequently allows any adhesions between fascial layers to be broken down restoring the tissue's suppleness (Sefton, 2004).

How to use a Foam Roller:

- Use over the muscular areas as shown overleaf
- Roll over the target area for 60 seconds
- Movement should be slow yet controlled
- Always avoid rolling over bone or bony areas

Mobility

FOAM ROLLING GLOSSARY

 Calf	 Outer lower leg
 Hamstrings	 Quadriceps
 ITB and outer thigh	 TFL
 Lower Back	 Upper Back

Neck Strengthening

THEORY AND EVIDENCE

Increasing neck strength reduces fatigue and potential injury during G exposure (Alricsson et al., 2004; Ang et al., 2005). (JET)

Neck strengthening exercises increases strength, function and reduces flight related neck pain in Rotary Aircrew (Ang et al., 2009). (ROTARY)

Participation in a specific neck strengthening program (such as the ACP) is seen as the most effective method of reducing the risk of neck injuries on both a short and long-term basis (Wickes and Greeves, 2006; Naish et al., 2013).

The aim of the ACP is to improve aircrew awareness of their neck position and use of the deeper core muscles when in their airframe to avoid overuse of, and ultimately injury.

The ACP uses head harnesses on a dual pulley system to improve the strength in the core muscles of the neck.

All exercises must be performed isometrically (where the muscle contracts but the neck remains in a static, neutral position). This will strengthen the neck muscles whilst reducing the shear that occurs through the discs in the neck, during movement (Mercer, 2005).

ACP MINIMUM END STATES

Stage	Minimum Standards to Progress
1	Can activate deep neck flexors Level 1 Theraband competent
2	Level 2A & B head harness competent
3	Level 3A & B head harness competent
4	Level 4A & B head harness competent

Neck Strengthening

LEVEL 1 EXERCISE GLOSSARY:

  	**Deep Neck Flexors** • Place the tongue on the roof of the mouth, lips together but teeth just separated • To complete the movement perform a gentle nodding of the head as if they were saying "yes" **If using a pressure bio-feedback:** • Place the folded cell (with studs closed) under the occiput • Gently nod to target 22mmHg, just one mark on the pressure dial (green band). Hold the position steadily • If successful, relax and repeat at each target position of 24mmHg through to 30mmHg (yellow, blue and grey bands) • The pressure that you can hold steadily, with minimal superficial muscle activity, is the one on which you will measure endurance capacity (i.e. 10 reps held for 6-10 sec each)
	**Theraband Isometric Extension** • Position theraband around your head just above ear level • Hold both ends firmly in front of your face so theraband is vertical • Activate DNFs • Slowly extend elbow maintaining spinal neutral **Hold for 10s and relax. Repeat 10 times**
	**Theraband Isometric Flexion** • Position theraband around the chin • Hold theraband firmly with the dominate hand above the head with the elbow bent at approx. 90degrees • Activate DNFs • Slowly extend elbow maintaining spinal neutral **Hold for 10s and return to start. Repeat 10 times**

Neck Strengthening

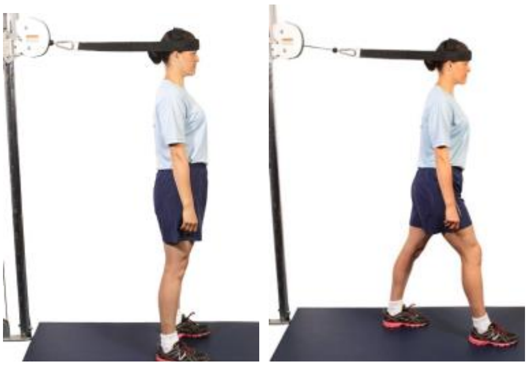
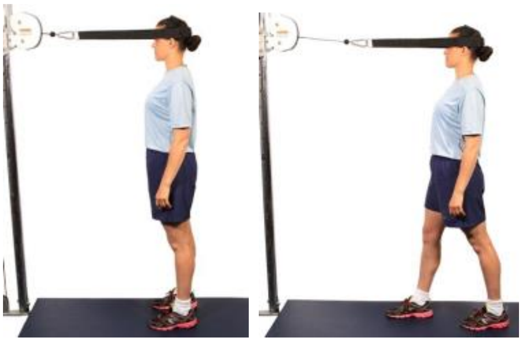
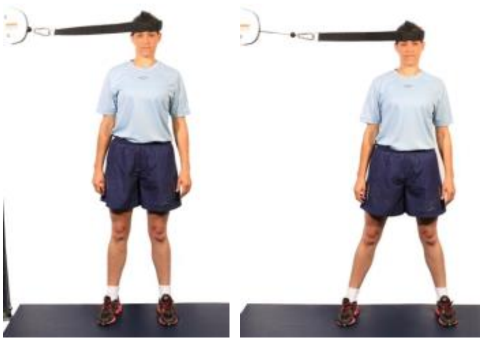
LEVEL 1 EXERCISE GLOSSARY CONTINUED:

	**Theraband Isometric Side Flexion** • Place theraband around the head as shown • Ensure there is no excessive twisting of the theraband • Hold both ends of the theraband firmly right of the face with your right hand so that theraband in horizontal to the floor • Activate DNFs • Slowly extend arm maintaining spinal neutral **Hold for 10s and relax. Repeat 10 times** **Repeat on the left side**

LEVEL 1 NECK STRENGTHENING NOTES:

Neck Strengthening

LEVEL 2A EXERCISE GLOSSARY

	**C/Spine Flexion, Forwards Walking** • Engage deep neck flexors (DNFs) and maintain neutral C/Spine • Ask partner to place loaded head harness as per illustration • Slowly walk forwards then backwards as far as the floor space allows **12 reps x 3sets. 30seconds rest between sets.**
	**C/Spine Extension, Backwards Walking** • Engage DNFs and maintain neutral C/Spine • Ask partner to place loaded head harness as per illustration • Slowly walk forwards and backwards as far as the floor space allows **12 reps x 3sets. 30seconds rest between sets.**
	**C/Spine Side Flexion, Sideways Walking** • Engage DNFs and maintain neutral C/Spine • Ask partner to place loaded head harness as per illustration • Slowly walk sideways as far as the floor space allows **12 reps x 3sets. 30seconds rest between sets.** **Repeat on other side**

Head Harness should be level or slightly higher than the pulley to prevent it slipping off the head.

Neck Strengthening

LEVEL 2B EXERCISE GLOSSARY

 	**C/Spine Flexion, Kneeling Trunk Flexion** • Engage deep neck flexors (DNFs) and maintain neutral C/Spine • Ask partner to place loaded head harness as per illustration • Slowly bend forwards at the hip as far as comfortable and controlled before returning to start position **12 reps x 3sets. 30seconds rest between sets.**
 	**C/Spine Extension, Kneeling Trunk Extension** • Engage DNFs and maintain neutral C/Spine • Ask partner to place loaded head harness as per illustration • Keeping your back and hips in line bend at the knees to tilt body backwards. **12 reps x 3sets. 30seconds rest between sets.**
 	**C/Spine Side Flexion, Kneeling Trunk Side Flexion** • Engage DNFs and maintain neutral C/Spine • Ask partner to place loaded head harness as per illustration • Slowly bend at the waist, flexing to the side • Move as far as comfortable before returning to start position **12 reps x 3sets. 30seconds rest between sets.** **Repeat on other side**

Head Harness should be level or slightly higher than the pulley to prevent it slipping off the head.

Neck Strengthening

LEVEL 3A EXERCISE GLOSSARY

	**C/Spine Extension, Squat & Shoulder Shrug** • Engage core and deep neck flexors (DNFs) to maintain neutral C/spine • Ask partner to place loaded head harness as per illustration, and to pass you 2 dumbbells • Perform a squat, keeping chest high • On return to standing perform a shoulder shrug and relax **12 reps x 3sets. 30seconds rest between sets.**
	**C/Spine Flexion, Lunge & Front raise** • Engage core and DNFs to maintain neutral C/spine • Ask partner to place loaded head harness as per illustration, and to pass you 2 dumbbells • Simultaneously perform a lunge, and front raise (<u>with both arms and thumbs pointing up</u>) • Return to standing whilst lowering arms **12 reps x 3sets. 30seconds rest between sets.** **Alternate leading leg**

LEVEL 3A EXERCISE GLOSSARY

C/Spine Side Flexion, Trunk Side Flexion & Shoulder Shrug

- Engage core and DNFs to maintain neutral C/spine
- Ask partner to place loaded head harness as per illustration, and to pass you 2 dumbbells
- Side flex to the left and return to standing, keeping a neutral spine throughout
- On return to standing perform a shoulder shrug and relax

12 reps x 3sets. 30seconds rest between sets.

Turn 180^{o} and repeat, flexing to the right

Head Harness should be level or slightly higher than the pulley to prevent it slipping off the head.

LEVEL 3B EXERCISE GLOSSARY

C/Spine Flexion, Bent Elbow Lateral Raise

- Sit on appropriately sized gym ball, feet shoulder width apart
- Engage core and deep neck flexors (DNFs) to maintain neutral C/spine
- Ask partner to place loaded head harness as per illustration, and to pass you 2 dumbbells
- Perform a bent elbow lateral raise

12 reps x 3sets. 30seconds rest between sets.

C/Spine Side Flexion, Alternate Bicep Curls

- Sit on appropriately sized gym ball, feet shoulder width apart
- Engage core and DNFs to maintain neutral C/spine
- Ask partner to place loaded head harness as per illustration, and to pass you 2 dumbbells
- Perform a bicep curls (left + right = 1 rep)

12 reps x 3sets. 30seconds rest between sets.

LEVEL 3B EXERCISE GLOSSARY

C/Spine Extension, Alternate Front Raise

- Sit on appropriately sized gym ball, feet shoulder width apart
- Engage core and DNFs to maintain neutral C/spine
- Ask partner to place loaded head harness as per illustration, and to pass you 2 dumbbells
- Perform an alternative front raise with your thumbs facing up

12 reps x 3sets. 30seconds rest between sets.

C/Spine Side Flexion, Single Arm Row

- Sit on appropriately sized gym ball, feet shoulder width apart
- Sit side on to one pulley while facing the other
- Engage core and DNFs to maintain neutral C/spine
- Ask partner to place loaded head harness as per illustration
- Perform a single arm row with your inside arm

12 reps x 3sets. 30seconds rest between sets.
Move 90^{o}, change arms and repeat

Head Harness should be level or slightly higher than the pulley to prevent it slipping off the head.

NECK STRENGTHENING EXERCISE NOTES:

Core Stability

THEORY AND EVIDENCE

Core stability refers to the body's ability to resist external forces in order to remain in the same position.

Core stability exercises are recommended to reduce the risk and prevalence of low back pain in aircrew (Gaydos, 2012; Llewellyn et al., 2010).

Core stability not only applies to the trunk but also the neck and shoulder. Stability exercises have been found to reduce the prevalence of neck pain in military aircrew personnel (Ang et al., 2009).

Exercises, such as back squats and deadlifts, elicit a high contraction from the trunk stabilisers (Comfort et al., 2011).

The ACP predominantly teaches trunk rotational stability exercises.

ACP MINIMUM END STATES

Level 1	Neutral posture in all positions
Level 2	Static rotation control in all positions
Level 3	Dynamic rotational control on a stable base
Level 4	Dynamic rotational control on an unstable base

Core Stability

LEVEL 1 – NEUTRAL POSTURE IN ALL POSITIONS

TVA Contraction in Crook lying

- Lying on your back with you knees comfortably bent, feet hip width apart and flat on the floor
- Find neutral pelvic/spine position
- Gently contract transversus abdominus and pelvic floor
- Hold for 10 seconds – keep breathing

10 reps with 5 sec rest after each

Overhead Arms

- Lying on your back with you knees comfortably bent, feet hip width apart and flat on the floor. Arms up pointing at the ceiling
- Find neutral pelvic/spine position
- Gently contract transversus abdominus and pelvic floor
- Slowly take one arm overhead towards the floor
- Do not let your back arch
- Slowly return to start
- Repeat on the other side

15-20 reps x 3-5sets with 10-30sec rest

Windmills

- Start position as per overhead arms
- Slowly take one arm overhead while taking the other to the floor
- With both arms on the floor, move them through an arc to reverse positions
- Slowly return to the start position
- Repeat in the other direction

15-20reps x 3-4 reps with 10-30 sec rest

Core Stability

LEVEL 1 – NEUTRAL POSTURE IN ALL POSITIONS

Crook Lying hip extensions

- Lying on your back with you knees comfortably bent, feet hip width apart and flat on the floor
- Find neutral pelvic/spine position
- Gently contract transversus abdominus and pelvic floor
- Slowly slide your leg straight out
- Then slide it back again
- Do not allow your back arch or flatten
- Repeat with the other leg

15-20 reps x 3-5 sets with 10-30sec rest

Bridging

- Lying on your back with you knees comfortably bent, feet hip width apart and flat on the floor. Arms up pointing at the ceiling
- Find neutral pelvic/spine position
- Gently contract transversus abdominus and pelvic floor
- Tilt pelvis backward and slowly peel your lower back off the floor
- Start at your lower back and continue until you are in a bridge
- Hold for 5 secs then reverse movement back to the start

15-20 reps x 3-5sets with 10-30sec rest

Four-point kneeling

- 4-point kneeling, knees under hips, hands under shoulders. Spine neutral
- Find neutral pelvic/spine position
- Gently contract transversus abdominus and pelvic floor
- Hold for 10 seconds – keep breathing

10 reps with 5 sec rest after each

Core Stability

LEVEL 1 – NEUTRAL POSTURE IN ALL POSITIONS

Sitting Series

- Sit, holding neutral posture and hands resting on thighs

- Raise one arm into shoulder flexion maintaining neutral spinal posture
- Return arm to the start position
- Repeat with your other arm

15-20 reps x 3-4 sets with 10-30 sec rest

- Perform Waiter's bow by placing one arm over the small of your back
- Place the other hand on your opposite shoulder
- Bend forward at the hips keeping your spine neutral
- Only travel through controlled range

15-20 reps x 3-4 sets with 10-30 sec rest

Standing Series

- Stand holding neutral posture

- Raise one leg with a flexed knee
- Take leg away from the mid line
- Lower leg to the starting point
- Repeat with your other leg

15-20 reps x 3-4 sets with 10-30 sec rest

- Perform Waiter's bow by placing one arm over the small of your back
- Place the other hand on your opposite shoulder
- Bend forward at the hips keeping your spine neutral
- Only travel through controlled range

15-20 reps x 3-4 sets with 10-30 sec rest

Core Stability

LEVEL 1 – NEUTRAL POSTURE IN ALL POSITIONS

Static Plank

- Prone position with your feet together and pivoting on your toes
- Rest on your elbow with your forearms directed forwards
- Straight line between hips, knees and ankles
- Find neutral pelvic/spine position
- Gently contract transversus abdominus and pelvic floor

Hold for 20-60sec x 3-5 with 20-60sec rest

LEVEL 1 CORE STABILITY NOTES:

Core Stability

LEVEL 2 – STATIC ROTATIONAL CONTROL IN ALL POSITIONS

Bent Knee Fall Out

- Lying on your back with you knees comfortably bent, feet hip width apart and flat on the floor
- Find neutral pelvic/spine position
- Gently contract transversus abdominus and pelvic floor
- Slowly drop one knee out to the side ensuring good pelvic control and posture is maintained
- Only travel through a controlled range
- Slowly return to the start and change legs

10-20 reps x 3-5 sets with 10-30 sec rest

Clam

- Side lying, hips and knees bent and vertically aligned. Ankle should be in line or slightly behind your bottom. Rest your head on your bottom arm
- Keeping your heels together slowly lift the top knee. Your pelvis must not rotate or tilt
- Hold for 2-3 seconds and slowly return to the starting position
- Only travel through a controlled range

10-20 reps x 3-5 sets with 10-30 sec rest

Side Lying Leg Lifts

- Side lying, spine and pelvis neutral with hips aligned vertically and legs stretched out long.
- Rest your head on your bottom arm and your top hand on the floor for stability
- Gently contract transversus abdominus and pelvic floor
- Slowly lift top leg as far as possible without the pelvis tilting then slowly lower to starting position. Do not allow spine or pelvis to twist

10-20 reps x 3-5 sets with 10-30 sec rest

Core Stability

LEVEL 2 – STATIC ROTATIONAL CONTROL IN ALL POSITIONS

3 Point Plank

- Adopting the same position as the static plank

- Maintaining neutral posture, carry out alternate shoulder flexion
- Return to the stable position each time

- Maintaining neutral posture, carry out alternate hip extension
- Return to the stable position each time

- With straight arms and maintaining neutral posture, carry out combine hip extension and alternate shoulder flexion
- Return to the stable position each time

20-50 sec holds x 3-5 sets with 20-60 sec rest

LEVEL 2 CORE STABILITY NOTES:

Core Stability

LEVEL 3 – DYNAMIC ROTATIONAL CONTROL ON A STABLE BASE

Four-Point Knealing Series

- 4-point knealing, knees under hips, hands under shoulders. Spine neutral
- Find neutral pelvic/spine position
- Gently contract transversus abdominus and pelvic floor

- Slowly raise one arm forward in line with your body. Slowly lower and repeat with the opposite arm

- Slowly extend one leg straight back in line with your body. Do not shift weight over stance leg or change the position of your lower back Slowly lower and repeat with the opposite leg

- Slowly lift opposite arm and leg in line with your body. Slowly lower and repeat with the opposite limbs

10-20 reps x 3-5 sets with 10-30 rest

Theraband Resistance Plank

- Same position as the static plank
- Get training partner to apply resistance through the Theraband
- Swap directions of pull

- To increase difficulty perform with 1 leg off the floor (as shown)

20-60 sec hold x 3-5 sets with 20-60 sec rest

LEVEL 3 – DYNAMIC ROTATIONAL CONTROL ON A STABLE BASE

Reverse Plank

- Supine position pivoting on your heels. Feet together, resting on your elbows with forearms directed forwards
- Hips, knees and ankles together
- Contract transversus abdominus and pelvic floor
- Lift hips so body is aligned

- Progress the exercise by lifting one leg off the floor (as shown)

Hold 20-60 sec x 3-5 sets with 10-30 sec rest

Side Plank

- Side lying position, resting on your elbow pivot on the outside of your lower foot to maintain 70-90 degrees at your shoulder
- Shoulder, hips, knees and ankles should all be aligned

- To progress slowly raise your upper leg and hold (as shown)

Hold 20-60 sec x 3-5 sets with 30-60 sec rest

Core Stability

LEVEL 3 – DYNAMIC ROTATIONAL CONTROL ON A STABLE BASE

High Plank Renegade Row

- Neutral posture, pelvis and shoulder level with floor, neutral head position. Dumbbells under shoulders
- Contract transversus abdominus and pelvic floor
- Keeping your trunk still with no rotation slowly row one arm up
- Slowly return and repeat with the opposite arm

- To progress increase resistance or place feet on a less stable surface

10-15 reps x 3-5 sets with 30-60sec rest

Low Plank Cable Row

- Neutral posture with your shoulders levels with the floor
- Support on your forearm reach the other hand forward and grasp the handle
- Slowly pull the handle towards your body in front of your shoulder
- Do not arch or rotate your trunk
- Slowly return to the start position

10-15 reps x 3-5 sets with 30-60sec rest

Change arms in between sets

LEVEL 3 – DYNAMIC ROTATIONAL CONTROL ON A STABLE BASE

Low Plank Side Cable Row

- In side plank position with neutral head posture
- Put your fully extended arm out in front to grasp handle
- Slowly pull the handle towards your body, in front of your shoulder
- Do not arch or rotate your trunk
- Slowly return to the start position

10-15 reps x 3-5 sets with 30-60sec rest

Change arms in between sets

Standing Woodchops

- Standing in a stable position with feet shoulder width apart. Neutral posture, elbows straight and scapula set
- Grip handle with both hands
- By rotating your trunk pull handle across you. Allow your eyes to follow your hands. Do not flex your trunk

10-15 reps x 3-5 sets with 30-60sec rest

Change arms in between sets

CORE STABILITY NOTES:

Strength Training

Strength training is recommended for fast jet pilots (Bateman et al., 2006).

Weight training has been shown to reduce flight related pain (Wickes and Greeves, 2006) and is recommended for Rotary Aircrew (Gaydos et al., 2012).

Strength training has been shown to improve pilot's ability to combat the considerable +Gz stresses within current high performance aviation environments (Bateman et al., 2006). This is achieved through improving the strength and endurance of the musculature involved in the anti-G straining manoeuvres (AGSM) (Bateman et al., 2006).

Flying posture can cause increased muscular activity, which can lead to fatigue-related pain (Gaydos, 2012).

ACP MINIMUM END STATES

Level 1	Initial technique instruction
Level 2	Competent in lifting technique
Level 3	Progression of weight whilst maintaining technique
Level 4	Further progression of weight

Strength Training

GENERAL LIFTING POINTS

Maintain a neutral spine throughout all movements

Do not allow the torso to flex

Do not allow the heels off the floor unless indicated

Valsalva technique = breathe in and hold tongue on roof of mouth against glottis

CONTENTS

- Back Squat
- Split Squat
- Bench Press
- Bent Over Row
- Front Squat
- Deadlift
- Push Press

- Kettlebells
    - Swings
    - Round the Body
    - Clean
    - Snatch
    - Goblet
    - Lunge
    - Deadlift
    - Romanian Deadlift
    - Military Press
    - Turkish Getup

- Powerbag
    - Clean
    - Gundrills

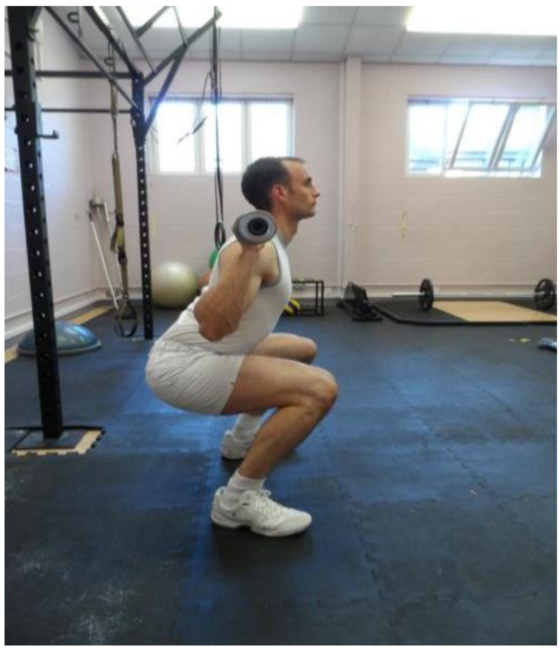
BACK SQUAT

Start Position

- Place the bar in a balanced position in the high bar position
- Hold the chest up and out
- Tilt the head slightly up
- Position feet shoulder-width apart, even with each other, with the toes turned slightly outward

Downward Movement

- Elbows high
- Chest up and out
- Allow the hips and knees to slowly flex while keeping the torso to floor angle relatively constant
- Keep the heels on the floor and the knees aligned over the feet
- Continue flexing the hips and knees until the thighs are parallel with the floor, the trunk begins to round or flex or the heels raise off the floor



(Courtesy of RAF Coningsby)

Upward Movement

- Extend the hips and knees, keeping the torso to floor angle constant
- Keep the heels on the floor and the knees aligned over the feet

(Referenced from Baechle et al., 2008)

SPLIT SQUAT

Start Position

- Step up to the bar and position the feet hip width apart and toes pointing forwards
- Place the bar on the shoulders in the high bar position
- Hold chest up and out
- Take a large step directly forwards with one leg
- Keep the trailing foot in the starting position but allow the knee to slightly flex

Downward Movement

- Allow the lead hip and knee to slowly flex
- Keep the lead knee directly over the lead foot
- Continue to flex the trailing knee until it is 1-2 inches above the floor
- Balance the weight evenly between both feet
- Keep the torso perpendicular to the floor by “sitting back” on the trailing leg

Upward Movement

- Forcefully push off the floor by extending the lead hip and knee
- Maintain the erect torso position
- Do not jerk the upper body backward
- Keep both feet in the starting position
- The lead knee should not move forward or backward
- The hips should describe a vertical movement

(Referenced from Baechle et al., 2008)

BENCH PRESS

Start Position

- Lie on the bench with feet on the floor, and your eyes below the racked bar
- Grasp the bar, slightly wider than shoulder-width apart
- Un-rack the bar with the help of a spotter
- Position the bar over the chest with the elbows fully extended

Downward Movement

- Lower the bar to touch the chest at approximately the nipple level
- Keep the wrists stiff and the forearms perpendicular to the floor and parallel to each other
- Maintain five-point body contact

Upward Movement

- Push the bar upward until the elbows are fully extended
- Keep the wrists stiff and the forearms perpendicular to the floor and parallel to each other
- Maintain five-point body contact position
- Do not arch the back or raise the chest to the bar
- Ask a spotter for assistance in racking the bar at the end of the set or if you are in difficulty
- Keep a grip on the bar until it is racked

(Referenced from Baechle et al., 2008)

BENT OVER ROW

Start Position

- Stand with the feet flat, shoulder width apart and the toes pointed slightly out
- Squat down to grip the bar, wider than shoulder width
- Create a neutral spine position, keep the torso-to-floor angle constant
- Lift the bar by extending the hips and knees, maintaining straight elbows
- Stop just before the knees are fully extended
- Focus the eyes a short distance ahead of the feet
- Allow the bar to hang with the elbows fully extended

Upward Movement

- Pull the bar towards the torso
- Keep the torso rigid, neutral spine and knees slightly flexed
- Do not jerk the torso upward
- Touch the bar to the lower chest or upper abdomen

Downward Movement

- Lower the bar to the starting position
- Maintain the neutral spine and knee position
- At the end of the set flex the hips and knees to place the bar on the floor

(Referenced from Baechle et al., 2008)

FRONT SQUAT

Start Position

- Step under the bar and place the hands in one of two arm positions
- Hold the chest up and out
- Un-rack the bar with the help of a spotter if needed
- Position the feet shoulder-width apart with the feet slightly turned out

Downward Movement

- Maintain a neutral spine with elbows high
- Hold chest up and out
- Allow the hips and knees to slowly flex
- Keep the torso-to-floor angle constant throughout the movement
- Keep the heels on the floor and the knees aligned over the feet
- Do not flex the torso or round the back
- Continue flexing the hips and knees until the thighs are parallel to the floor

Upward Movement

- Maintain a neutral spine with the elbows high and the chest up and out
- Extend the knees and hips, maintaining the torso-to-floor angle
- Keep the heels on the floor and the knees aligned over the feet
- Do not flex the torso or round the back
- Continue extending the hips and knees to reach the starting position

(Referenced from Baechle et al., 2008)

DEADLIFT

Start Position

- Stand with the feet flat, shoulder width apart and the toes pointed slightly out
- Squat down with the hips lower than the shoulders
- Place hands on the bar slightly wider than shoulder width, outside the knees with the elbows fully extended
- Grasp the bar with an alternated grip
- Place the feet flat on the floor with the bar approximately 1 inch in front of the shins over the balls of the feet
- Position the head and spine in a neutral alignment
- Chest up and out
- Shoulders over or slightly in front of the bar
- Eyes focused slightly ahead but not upward

Upward Movement

- Lift the bar by extending the hips and knees
- Keep the torso-to-floor angle constant
- Do not let the hips raise before the shoulders
- Maintain a neutral spine
- Keep the elbows fully extended and the shoulders over the bar
- As the bar is raised, keep it as close to the shins as possible
- As the bar rises just above the knees, move the hips forward to move the thighs and knees under the bar
- Continue to extend the hips and knees until the body reaches a fully erect position

Downward Movement

- Allow the hips and knees to flex to slowly lower the bar to the floor
- Maintain a neutral spine, do not flex the torso forward

(Referenced from Baechle et al., 2008)

PUSH PRESS

Start Position
- Grasp the bar slightly wider than shoulder width
- Place the bar on top of the anterior deltoids and clavicles
- Un-rack the bar and take a step or two backwards
- Position the feet shoulder width apart (or wider), with the toes slightly pointed out

Dip Phase
- Flex the hips and knees at a slow to moderate speed to move the bar in a straight path downward
- Continue to dip for approximately 10% of the athletes height
- Keep the feet flat on the floor, torso erect and the upper arms parallel to the floor

Drive Phase
- Immediately upon reaching the lowest position of the dip, reverse the movement by forcefully and quickly extending the hips and knees and then the elbows to move the bar overhead

Catch Phase
- After the hips and knees are fully extended and the bar is overhead from the drive phase, press it up the rest of the way until the elbows are fully extended
- Maintain spinal neutral, do not over extend the spine

Downward Movement
- Lower the bar by gradually reducing the muscular tension of the arms to allow a controlled decent of the bar to the shoulders
- Simultaneously flex the hips and knees to cushion the impact of the bar on the shoulders

(Referenced from Baechle et al., 2008)

KETTLEBELLS – HEALTH AND SAFETY

Description
- Ensure sore is contracted during the movement
- Ensure your back is not arched or rounded
- Ensure you have a firm base of support
- Ensure concentration for all lifts

Coaching Points
- Keep your weight through your heels
- Drive though your hips
- Keep your arms relaxed
- Keep a firm grasp of the KB (exercise dependent)

Spotting
- When spotting your training partner, support them under their elbows
- Assistance can also be given for balance exercises also
- Be aware of your partners movement and the direction of KB travel

(Referenced from KBT Education; kbteudcation.co.uk)

KETTLEBELL EXERCISE GLOSSARY

Kettlebell Swings 1 or 2 hands

- Start with your feet shoulder width apart, knee slightly bent. Keep the weight through your heels. Set your core and maintain throughout
- Maintaining neutral spine and relaxed arms drive your hips forwards and knees straight
- Keeping a pendulum momentum bend your hips back to the starting position
- **Do not let your back bend during this exercise, especially when lowering**

Coaching Points – Core Set. Firm Grip. Neutral Spine.

(Referenced from KBT Education; kbteudcation.co.uk)

KETTLEBELL EXERCISE GLOSSARY

Kettlebell Round the Body

- Start with your feet shoulder width apart, knee slightly bent. Keep the weight through your heels. Relax your arms
- Set and maintain your core and neutral spine alignment throughout
- Keeping a pendulum momentum pass the kettle bell around your body from hand to hand
- **Do not let your back bend during this exercise**

Coaching Points – Core Set. Neutral Spine.

(Referenced from KBT Education; kbteudcation.co.uk)

KETTLEBELL EXERCISE GLOSSARY

Kettlebell Clean

- Keeping a narrow stance with your knees slightly bent. Weight through your heels and arms relaxed
- Set and maintain your core and neutral spine alignment throughout
- Drive through your hips and thighs into an upright position.
- **Do not let your back bend during this exercise, especially when lowering**

Coaching Points – Core Set. Relaxed Arms. Neutral Spine.

(Referenced from KBT Education; kbteudcation.co.uk)

KETTLEBELL EXERCISE GLOSSARY

Kettlebell Snatch

- Start as per swing position
- Maintaining neutral spine and relaxed arms drive up snapping your hips forward. **Do not let your back over extend.**
- During the swing bend your exercising elbow and allow the KB to come to shoulder height.
- At shoulder height with arm full bent flip the wrist over and punch KB above head in one one movement
- Descend in a controlled return motion
- **Do not let your back bend during this exercise, especially when lowering**

Coaching Points – Core Set. Firm grip then release to claw grip. Neutral Spine and straight back.

(Referenced from KBT Education; kbteudcation.co.uk)

Strength Training

KETTLEBELL EXERCISE GLOSSARY

Kettlebell Goblet

- Keeping a narrow stance with your knees slightly bent. Weight through your heels and arms relaxed
- Set and maintain your core and neutral spine alignment throughout
- Hold the DB firmly at chest level
- Descend under control. Knees do not need to go beyond 90degrees bend
- **Your back must stay controlled throughout**
- Drive upwards to start position

Coaching Points – Core Set. Firm Base. Neutral Spine. Raise elbows away from your side.

Kettlebell Lunge

- Stand with your feet shoulder width apart. Core set with a firm base of support
- Keeping upright and your back straight take a step forward and lunge your bottom knee down (as seen in the picture)
- Ensure your knee is of good alignment with its hip, ankle and toes
- Your knee should not travel forward beyond your foot
- Push back from the lunge into standing. Repeat with the opposite leg

(Referenced from KBT Education; kbteudcation.co.uk)

KETTLEBELL EXERCISE GLOSSARY

Kettlebell Deadlift

- Start as per clean position but with 2 hands on the kettlebell
- Kettlebell in hammer position
- Keeping your core set, neutral spine alighnement and a firm base drive upwards
- Maintain kettlebell close to your body
- Descend under control
- **Your back must stay controlled throughout**

Coaching Points – Core Set. Relaxed Arms. Neutral Spine.

Romanian Deadlift

- Standing shoulder width apart. Set your core
- With a firm base keeping your back straight lean forward raising non exercising leg to the rear (as shown)
- Push from lunge back to standing
- Repeat with the opposite leg

Coaching Points – Keep knee over your toes. Use free arm to assist balance. Keep back straight throughout.

(Referenced from KBT Education; kbteudcation.co.uk)

KETTLEBELL EXERCISE GLOSSARY

Military Press

- From the ‘top’ of the clean position but with a slightly narrower base of support.
- With your core set push the kettlebell up
- Keep your elbow away from the side of your body
- Extend arm overhead without over extending your back
- Return to start position under control

Coaching Points – Core set. Do not over extend your back. Keep your eyes on the kettlebell throughout.

(Referenced from KBT Education; kbteudcation.co.uk)

KETTLEBELL EXERCISE GLOSSARY

Turkish Getup

- Start in a supine position with the kettlebell in an extended arm
- Fully extend the arm whilst sliding the leg into a flexed position
- Sit up and lean onto your forearm
- Push from your forearm onto your hand
- Slide your leg under and behind your opposite leg. Push from your hand into a kneeling lunge position
- Move to standing

Maintain a neutral spine throughout

Slowly return to supine lying

Coaching Points – Core set. Focus your eyes on the Kettlebell. Ensure a continuous movement from start to finish position.

(Referenced from KBT Education; kbteudcation.co.uk)

POWERBAG EXERCISE GLOSSARY

Clean

- Feet hip width apart, toes forward. Set your core.
- Squat down and with arms extended grasp the bag at the handles
- Keeping the powerbag close to you extend your hips with a forceful motion
- Shrug your shoulders and keeping your elbows out raise the powerbag to your chest at shoulder height
- Return to start position under control
- **Maintain neutral spine throughout**

Coaching Points – Core set. Maintain neutral spine.
Keep your eyes focused straight ahead and slightly upwards.

Strength Training

POWERBAG EXERCISE GLOSSARY

Gundrills

- Feet hip width apart, toes forward. Set your core.
- Squat down and with arms extended grasp the bag at the handles
- Keeping the powerbag close to you extend hips with a forceful motion. Your shoulder must rise before your hips
- Shrug your shoulders and keeping your elbows out lunge (as shown)
- Then simultaneously extend and jump with a forceful motion
- Land and return to a lunge position with the opposite leg forward
- **Maintain neutral spine throughout**

Coaching Points – Core set. Maintain neutral spine.
Keep your eyes focused straight ahead and slightly upwards.

Strength Sessions

SAMPLE STRENGTH SESSION 1:

Exercise	Set 1		Set 2		Set 3		Set 4	
	Reps	Weight	Reps	Weight	Reps	Weight	Reps	Weight
Back Squat	5		5		5		5	
Split Squat	5		5		5		5	
Bench Press	5		5		5		5	
Bent Over Row	5		5		5		5	

Weight = 60-80% of 1 rep max   30-60s rest between sets

SAMPLE STRENGTH SESSION 2:

Exercise	Set 1		Set 2		Set 3		Set 4	
	Reps	Weight	Reps	Weight	Reps	Weight	Reps	Weight
Front Squat	5		5		5		5	
Deadlift	5		5		5		5	
Chin Up	5		5		5		5	
Push Press	5		5		5		5	

Weight = 60-80% of 1 rep max   30-60s rest between sets

Strength Sessions

SAMPLE STRENGTH SESSION 3:

Exercise	Set 1 Left Arm		Set 2 Right Arm		Set 3 Left Arm		Set 4 Right Arm	
	Reps	Weight	Reps	Weight	Reps	Weight	Reps	Weight
KB Swing	20		20		20		20	
One Arm KB Press	10		10		10		10	
Turkish Getups	10		10		10		10	
One Arm KB High Pull	10		10		10		10	

30-60s rest between sets

SAMPLE STRENGTH SESSION 4:

Exercise	Set 1 Left Arm		Set 2 Right Arm		Set 3 Left Arm		Set 4 Right Arm	
	Reps	Weight	Reps	Weight	Reps	Weight	Reps	Weight
One Arm KB Clean	5		5		5		5	
One Arm KB Snatch	5		5		5		5	
KB Swing	20		20		20		20	
Turkish Getups	5		5		5		5	

30-60s rest between sets

Cardiovascular Training

THEORY

Cardiovascular metabolic conditioning sessions are included in the programme and are intended to increase the storage and delivery of energy for any activity.

Physical conditioning offers aircrew benefits in an aviation environment (Bateman et al., 2006).

Anaerobic training can enhance the body’s ability to prevent G-LOC by improving venous return to the brain (Balldin, 1985).

Excessive aerobic fitness may be deleterious to G-tolerance and it is recommended that fitness training should not be pursued so far as to cause the resting heart rate to fall below 55 beats/min (Green, 2006).

Rotary aircrew who perform aerobic exercise regularly suffer less neck pain (Wickes and Greeves, 2006).

Ensure a thorough warm up is performed prior to each anaerobic workout.

An effective cool down post exercise should also be performed, including gentle jogging and static stretches.

There now follows some sample sessions you may wish to utilise.

SAMPLE SESSIONS

SESSION 1

Exercise	Sets	Rest between Sets
300m Row	10	60 secs

SESSION 2

Exercise	Sets	Rest between Sets
500m Row	10	90 secs

SESSION 3

Exercise	Sets	Rest between Sets
400m Run	8	2 Mins

SESSION 4

Exercise	Notes
100 Thrusters	15-30kg barbell
5 Burpees	On the minute, every minute until all thrusters are completed

SAMPLE COMBINED SESSIONS

SESSION 5

Set	Exercise
1	500m row – 10 KB swings – 10 Burpees
2	400m row – 12 KB swings - 12 Burpees
3	350m row – 15 KB swings – 15 Burpees
4	250m row – 18 KB swings – 18 Burpees
5	500m row
Notes	Rest while partner is working

SESSION 6

<table>
<tr><th>Set</th><th>Reps</th><th>Exercises</th></tr>
<tr><td>1</td><td>21</td><td rowspan="3">Dumbell Squat and Press
Chest to floor Burpees
Sit ups</td></tr>
<tr><td>2</td><td>15</td></tr>
<tr><td>3</td><td>9</td></tr>
<tr><td>Notes</td><td colspan="2">Complete reps on all 3 exercises
Rest while partner is working</td></tr>
</table>

SAMPLE COMBINED SESSIONS

SESSION 7

Rep	Exercise
1	Kettlebell swings
2	Burpees with Press Up
3	Deadlift with Powerbag
4	Sit Ups
5	400m Treadmill Run
Notes	Complete all reps for 1 set. Rest when partner works Repeat for 5 sets

SAMPLE COMBINED SESSIONS

SESSION 8

Exercise	Description	Reps
Run	On Treadmill or Outside	400m
Kettlebell	Turkish Get ups	20
Powerbag	Clean and Press	20
Kettlebell	Single arm swings	20
Powerbag	Gundrills	20
Kettlebell	Clean and Press	20
Run	On Treadmill or Outside	400m
Notes	To be completed twice through	

NOTES

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Ministry of Defence
Research Ethics Committee

From the Chairman
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Telephone: 0121 507 4123
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Sq Ldr Ellen Slungaard Physiotherapy Research Officer Aviation Medicine Wing RAF Centre of Aviation Medicine RAF Henlow, Bedfordshire, SG16 6DN	Our Reference: 523/MODREC/14 Date: 16 November 2014

Dear Sq Ldr Slungaard,

Does a structured Aircrew Conditioning Programme enhance pilot performance within a high +Gz environment?

Thank you for submitting your revised Protocol 523 with tracked changes, and with a covering letter with responses to my own letter. The revised protocol has been approved by the Officers of MODREC ex-Committee, though you will note that Section 7 has been changed.

I wish you and your colleagues a successful study. In due course please send the Secretariat a final report containing a summary of the results so that these can be filed in accordance with the arrangements under which MODREC operates**.** Please would you also send a brief interim report in one year's time if the study is still ongoing.

This approval is conditional upon adherence to the protocol – please let me know if any amendment becomes necessary.

Yours sincerely

Allister Vale

Allister Vale MD FRCP FRCPE FRCPG FFOM FAACT FBTS FBPhamacolS FEAPCCT Hon FRCPSG

cc Professor David Jones, Professor David Baldwin, Marie Jones

Appendix 4

Information for Participants

Study title

Does a structured Aircrew Conditioning Programme enhance pilot performance within a high +Gz environment?

Invitation to take part

You are being asked to volunteer for a research study. Before you decide to volunteer, it is important for you to understand why the research is being undertaken and what you will be asked to do as a volunteer. Please take time to read the following information carefully and discuss it with others if you wish. If, after reading the information below, you are interested in volunteering for the study, please contact the Chief Investigator (Sqn Ldr Ellen Slungaard) by email and she will explain the details of the study to you personally and answer any questions you may have. After this you will be given at least 24 h to consider your decision as to whether or not you wish to volunteer.

What is the purpose of the research?

The ability of aircrew to operate in the modern high-performance aircraft environment requires the need to tolerate the considerable +Gz stressors. This involves the ability to perform an effective anti-G straining manoeuvre (AGSM) and being able to move and conduct lookout in a high +Gz environment. Physical conditioning may be an effective modality for increasing this ability.

The purpose of this research is to provide evidence as to whether a targeted and structured Aircrew Conditioning Programme (ACP) will have a beneficial effect on the operational effectiveness of pilots within the Royal Air Force. Pilot performance may be enhanced through improvements in the ability to perform repeatedly an effective anti-G straining manoeuvre and by a reduction in the magnitude and incidence of flying related musculoskeletal injury. In turn, this may provide improved cockpit mobility for lookout, leading to better combat performance.

Who is doing this research?

This research project is being organised by the Royal Air Force Centre of Aviation Medicine, conducted by Squadron Leader Ellen Slungaard, Royal Air Force Physiotherapy Research Officer and supervised by Wing Commander Nic Green, Royal Air Force Consultant in Aviation Medicine. The work is being funded by the UK Ministry of Defence and forms part of a PhD for the Chief Investigator, with the full support of RAF Centre of Aviation Medicine.

Why have I been invited to take part?

You have been asked to participate because you are an RAF or Naval Aircrew either enrolled on the RAF Basic Fast Jet Training Course or an RAF Aircrew Holding Officer.

Do I have to take part?

No, you do not have to take part. Participation is purely voluntary. Whether you decide to take part or not, will in no way influence any assessment of your performance within the flying training pipeline.

You can withdraw from the study at any time without giving a reason. If you have further questions or wish to speak to the the Chief Investigator, please do not hesitate to ask.

What will I be asked to do?

You will first be required to complete a Medical Screening Questionnaire and your current Medical Employment Standard will be confirmed through review of your aircrew logbook. You will also be required to confirm that you are in-date the RAF Fitness Test (RAFFT). Your on-going fitness to particpate will also be confirmed before each experimental visit. You will then be asked to complete an Aircrew Neck Pain and Lifestyle Questionnaire. This will take approximately 30 minutes.

Phase 1: This phase involves collection of baseline demographics (height, weight, hand dominance, neck circumference) at RAF Linton-on-Ouse. You will also have the measurements described in Table 1 taken. These measurements will be performed by the Chief Investigator, a Physiotherapist and a Physical Training Instructor (PTI). This Phase will take approximately 2 hours.

Table 1. Measurements to be taken at RAF Linton-on-Ouse

What?	**How?**
Neck range of motion, neck muscle strength and neck muscle endurance	With a machine called the Multi-Cervical Unit. You will be sat in an upright posture and will actively move your head for range of motion, and actively push against a padded load cell for strength and endurance.
Whole body movement control	Functional Movement Screen (FMS) which is a test comprised of 7 specific movement patterns that require a balance of mobility and stability.
Anaerobic capacity	Running-based Anaerobic Sprint Test (RAST) which involves six times 35m discontinuous sprints. Each sprint represents a maximal effort with 10 seconds recovery between each. The time for each sprint is recorded.
Strength	Muscular strength and endurance assessment of the most important muscles for anti-G straining manoeuvre performance. This will involve performing a 1 Repetition Maximal of the following exercises - double leg press (leg muscles), bar bell flat bench press (chest muscles), timed plank to failure (sub-maximal endurance measure of core/abdominal muscles – lying on your front with your forearms on the ground, keeping elbows under shoulders and feet together. Raise the body upward off the floor and hold this position with the body in a straight line).

Phase 2: This phase will occur at the QinetiQ Centrifuge in Farnborough and you will be wearing the current Hawk T1 anti-G suit and Mk10R helmet. You will also wear inflatable foot bladders which are an optional item for the Typhoon. You will be monitored continuously throughout the experimentation using the measurement

techniques outlined in Table 2 and a Supervising Medical Officer (SMO) who will be sat in a seat located at the centre of the centrifuge will be in continuous audio and video contact with you throughout. This Phase will involve a full day at the centrifuge.

Table 2. Measurements to be taken at the QinetiQ Centrifuge, Farnborough

What?	How?
Heart rate	From three adhesive patches placed on your chest.
Ear blood content	From a sensor clipped to your ear.
Amount of oxygen in your blood	From a sensor clipped to your finger.
Electrical activity of your neck, abdominal and leg muscles	From adhesive electrodes attached to the muscles of your neck, abdomen and legs.
Amount of force exerted through the foot pedals	From a load cell attached to the foot pedal in the centrifuge gondola.
Breathing rate/volume	From the rate of gas coming into and out of your mask.
Amount of lactate in your blood	From a finger prick blood sample.
Rating of percieved exertion	By scoring the levels of exertion required to maintain an effective anti-G straining manoeuvre (AGSM).

You will be asked to undertake four sets of centrifuge exposures:

Run 1 – Resting G Tolerance: You will be asked to undertake a gradual onset acceleration exposure in which the centrifuge will be accelerated slowly (increasing by 1G every 10 seconds). You will remain relaxed throughout and will asked to fixate on a central white light and depress the 'stop' button when the red lights are no longer percieved. The red lights are positioned at a 15^{o} angle to your eyes. Depressing the stop button will initiate centrifuge deceleration and will allow the Chief Investigator/SMO to estimate your relaxed G tolerance (RGT).

Run 2 – Straining G Tolerance: You will be asked to undertake a centrifuge exposure consisting of a stepped protocol starting at +2.8Gz for 15 seconds, then increasing every 5 seconds thereafter in 0.4 increments until you terminate the run by depressing the 'stop' button. In this run the centrifuge will reach each +Gz level at a rate of 1G every second. You will remain relaxed until you lose the peripheral red lights and thereafter tense your leg and abdominal muscles as much as needed to maintain clear vision. You will terminate the run when you are unable to maintain clear vision through straining and this G level will indicate your straining +Gz tolerance. You will complete two runs with the average of the two +Gz levels obtained used in subsequent analysis.

Run 3 – Simulated Air Combat Manoeuvres (SACM): This will involve four cycles of 15 seconds at +5Gz followed by 5 seconds at +7Gz. You will be asked to initiate the AGSM in order to maintain fully clear vision throughout the exposure. You will be wearing anti-G trousers which will inflate under +Gz to assist you to maintain clear vision. After completion of the four cyles, you will be asked if you wish to continue into Run 4. You may stop the centrifuge at any point.

Run 4 – Simulated Air Combat Manoeuvres (SACM) to volitional end: This will involve repeated cycles of the SACM described in Run 3 with 2 minutes rest between each cycle until you are unable to initiate an effective AGSM to maintain clear vision, or become exhausted. You may stop the centrifuge at any point.

Before any of the accleration exposures you will be asked to tense your stomach, leg and neck muscles as hard as you can for a brief period (10 seconds). This will allow the chief investigator to measure the amount of force your muscles can generate. The electrical activity they produce will also be recorded via electrodes placed on your skin over the muscles. Before the first acceleration exposure, after Run 3 and, if you continue, after Run 4, you will be asked to push against the rudder bar in the gondola to a pressure equivalent to 30% of your maximum and hold this level for as long as possible. To help you do this the pressure applied to the pedals will be measured and displayed in front of you on a computer screen.

Following completion of the centrifuge exposures you will then be allocated to one of two pre-assigned groups. Group 1 will complete the ACP and Group 2 will be advised to continue with their current established exercise regimen. This will last for a 12 week period, after which both groups will repeat the testing in Phases 1 and 2.

Inclusion Criteria
To take part in this study, you should be:

- aged between 18 and 30 years old;
- in good health;
- existing RAF or Naval Aircrew either enrolled on the RAF Basic Fast Jet Training Course at RAF Linton-on-Ouse, or a Holding Officer waiting to commence the Elementary Flying Training Course at RAF Cranwell.

You must also have experience riding the Farnborough centrifuge and be familiar with the following:

- measurement (by reference to subjective visual symptoms) of relaxed G tolerance using both gradual onset runs and rapid onset runs;
- use of Hawk aircrew equipment on the centrifuge;
- performance of the anti-G straining manouevre;
- exposure to increased +Gz acceleration up to and including +7 Gz.

or be willing to undertake a centrifuge training programme that includes familiarisation with all the activities described above.

If you do not already have sufficient experience on the centrifuge, full training will be provided before you are asked to participate in the study itself.

You must also be willing to comply with the following instructions:

- go without vigorous exercise for at least 48 hours prior to any visit to the centrifuge;
- not to take any form of medication or other drug (prescribed or non-prescribed, with the exception of paracetamol) from 24 hours prior to the start of the centrifuge phase of the study until its completion;
- not to drink more than two pints of beer, two measures of spirits or two glasses of wine on the evenings prior to visiting the centrifuge and consume no alcohol after midnight;
- arrive at the centrifuge well rested and without having missed any meals that you would normally take.

What are the benefits of taking part?

There are no direct benefits to you but this research will improve and add to the current knowledge base regarding the strategies employed to enhance aircrew performance operating in a high G environment.
It will help you through improved awareness of and participation in conditioning programmes including neck strengthening, which may improve performance in a high G environment, and increased practice of the anti-G straining manoeuvre.

What are the possible disadvantages and risks of taking part?

Sustained acceleration
Exposure to sustained periods of increased +Gz acceleration is associated with several hazards:

- A 'dimming' of vision (grey-out), which may lead to temporary loss of vision (black-out) or even loss of consciousness (G-LOC) – the risk of G-LOC is very low as you, the medical officer and the control team have access to emergency stop switches, which will rapidly terminate the centrifuge run;
- Minor skin rash – this is harmless and disappears after a few days;
- Disorientation (and possibly nausea), usually during and immediately after the deceleration phase of the centrifuge run;
- An increased heart rate and occasionally an abnormal heart rhythm, when exposed to +Gz acceleration – these are usually transient and have no ill-effects;
- Possible neck and upper spine injury - the risks of these injuries occurring are low as you will not be moving your head during runs and it will be supported by the head box;
- Discomfort from the inflated anti-G garments;
- Fatigue from repeated performance of the anti-G straining manoeuvre – the medical officer will assess your fitness following every run.

There are, however, no known long-term effects of exposure to increased +Gz acceleration.

Fingertip blood sample
You will feel a sharp scratch when the needle enters your finger tip – this will only be temporary and any bleeding will stop quickly. The area might be slightly sore to touch for a day or two afterwards.

Can I withdraw from the research and what will happen if I don't want to carry on?

You can withdraw from the study at any time and are under no obligation to provide your reasons for doing so, or attend for further experimentation.

Are there any expenses and payments, which I will get?

You will not be paid for your participation in this study but any expenses incurred during your involvement in this study will be recompensed.

Will my taking part or not taking part affect my Service career?

While in general, participation (or not) will not affect your career, there is the potential for the screening medical or ECG to identify potentially career restricting abnormalities, although knowledge of these may enhance your future safety.

In such an event this will be managed by your Service GP.

Whom do I contact if I have any questions or a complaint?

If you have any questions please contact the Chief Investigator, Sqn Ldr Ellen Slungaard at ellen.slungaard421@mod.uk or on 01462 851515 x 6460. If you would prefer not to contact the Chief Investigator, you may contact the Ministry of Defence Research Ethics Committee Secretary.

What happens if I suffer any harm?

In the extremely unlikely event of you suffering any adverse effects as a consequence of your participation in this study, you will be eligible to apply for compensation under the 'No Fault Compensation Scheme' of Ministry of Defence, administered by the DBR Common Law Claims & Policy (CLCP), Ministry of Defence, Level 1, Spine 3, Zone J, Whitehall, London, SW1A 2HB who may need to ask the Claimant to be seen by a MOD medical adviser.

What will happen to any samples I give?

You will be asked to provide several blood samples (from finger pricks) during the study. These samples will be destroyed once analyses are complete.

Will my records be kept confidential?

Any information obtained during this study will remain confidential as to your identity: if it can be specifically identified with you, your permission will be sought in writing before it will be published. Other material, which cannot be identified with you, may be published or presented at meetings with the aim of benefiting others. You have a right to obtain copies of all papers, reports, transcripts, summaries and other material so published or presented on request to the Chief Investigator. All information will be subject to the current conditions of the Data Protection Act 1998. Experimental records, including paper records and computer files, will be held for a minimum of 100 years in conditions appropriate for the storage of personal information. You have right of access to your records at any time.

Further information and contact details.

If you require further information you should contact:

Squadron Leader Ellen Slungaard – Chief Investigator
RAF Centre of Aviation Medicine
Royal Air Force Henlow
Bedfordshire SG16 6DN
Tel: 01462 851515 x 6460
Email: Ellen.Slungaard421@mod.uk

Mrs Marie Jones - Ministry of Defence Research Ethics Committee Secretary
Corporate Secretariat
Bldg 005, G01-614
Dstl Porton Down

Salisbury
Wiltshire SP4 0JQ
Tel: 01980 658155
Email: ethics.sec@dstl.gov.uk

Compliance with the Declaration of Helsinki.

All research on MOD/Service personnel is looked at by an independent group of people, called a Research Ethics Committee, to protect your safety, rights, wellbeing and dignity. The Royal Air Force Experimental Medicine Scientific Advisory Committee also initially reviews this study. This study has been reviewed and approved by the MOD Research Ethics Committee (General).

This study complies, and at all times will comply, with the Declaration of Helsinki[1] as adopted at the 64th WMA General Assembly at Fortaleza, Brazil in October 2013[1]. Ask the Chief Investigator if you would like further details of the approval or to see a copy of the full protocol.

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[1] World Medical Association Declaration of Helsinki [revised October 2013]. Recommendations Guiding Medical Doctors in Biomedical Research Involving Human Subjects. 64th WMA General Assembly, Fortaleza (Brazil).

ARRANGEMENTS FOR THE PAYMENT OF NO-FAULT COMPENSATION TO RESEARCH PARTICIPANTS

1. This Annex sets out the arrangements for the payment of no-fault compensation to a person who suffers illness and/or personal injury as a direct result of participating in research conducted on behalf of the Ministry of Defence. The no-fault compensation arrangements only apply to research participants (Military, Civilian, or non-Ministry of Defence) who take part in a Trial that has been approved by the MOD Research Ethics Committee.

2. A research participant wishing to seek no-fault compensation under these arrangements should contact the DBR Common Law Claims & Policy (CLCP), Ministry of Defence, Level 1, Spine 3, Zone J, Whitehall, London, SW1A 2HB who may need to ask the Claimant to be seen by a MOD medical adviser.

3. CLCP will consider reasonable requests for reimbursement of legal or other expenses incurred by research participants in relation to pursuing their claim (e.g. private medical advice, clinical tests, legal advice on the level of compensation offered) provided that they have been notified of the Claimant's intention to make such a Claim.

4. If an injury is sufficiently serious to warrant an internal MOD inquiry, any settlement may be delayed at the request of the research participant until the outcome is known and made available to the participant in order to inform his or her decision about whether to accept no-fault compensation or proceed with a common law claim. An interim payment pending any inquiry outcome may be made in cases of special need. It is the Claimant's responsibility to do all that he or she can to mitigate his or her loss.

5. In order to claim compensation under these no-fault arrangements, a research participant must have sustained an illness and/or personal injury as a direct result of participation in a Trial. A claim must be submitted within three years of when the incident giving rise to the claim occurred, or, if symptoms develop at a later stage, within three years of such symptoms being medically documented.

6. The fact that a research participant has been formally warned of possible injurious effects of the trial upon which a claim is subsequently based does not remove MOD's responsibility for payment of no-fault compensation. The level of compensation offered shall be determined by taking account of the level of compensation that a court would have awarded for the same injury, illness or death had it resulted from the Department's negligence.

7. In assessing the level of compensation, CLCP, in line with common law principles, will take into account the degree to which the Claimant may have been responsible for his or her injury or illness and a deduction may be made for contributory negligence accordingly.

8. In the event of CLCP and the injured party being unable to reach a mutually acceptable decision about compensation, the claim will be presented for arbitration to a nominated Queen's Counsel. CLCP will undertake to accept the outcome of any such arbitration. This does not affect in any way the rights of the injured party to withdraw from the negotiation and pursue his or her case as a common law claim through the Courts.

Appendix 5

PROTECT - MEDICAL (when completed)

HEALTH SCREEN FOR STUDY VOLUNTEERS

Does a structured Aircrew Conditioning Programme enhance pilot performance within a high +Gz environment?

Name…………………………………………..……

This questionnaire is to ensure that you are in good health and have no medical problems which might influence your own wellbeing as a result of participation in the trial, or influence the results of the trial.

Please complete the following questions to confirm fitness to participate:

1. **At present**, do you have any health problem for which you are:
   (a) on medication, prescribed or otherwise……………………………Yes No
   (b) attending your general practitioner/physician…………..……… Yes No
   (c) on a hospital waiting list……………..……………………………... Yes No

2. **In the past two years**, have you ever had any illnesses which required you to:
   (a) consult your GP/physician……….………………...…………….. Yes No
   (b) attend a hospital outpatient department…………………………... Yes No
   (c) be admitted to hospital………………..…………………………….. Yes No

3. **Have you ever** had any of the following:
   (a) Convulsions/epilepsy…………………………………………………Yes No
   (b) Asthma……………………………….…………………………..……. Yes No
   (c) Eczema……………………………….……………………….……. Yes No
   (d) Diabetes……………………………………...……...….………. Yes No
   (e) A blood or blood vessel disorder……………………...…………. Yes No
   (f) Head injury……………………………………………….………........ Yes No
   (g) Digestive problems……………………………………………..…… Yes No
   (h) Heart problems……………………………………………………… Yes No
   (i) High blood pressure……………………………………………..…… Yes No
   (j) Problems with bones or joints…………………………………….…… Yes No
   (k) Decompression sickness ('The Bends')......………..………….……. Yes No
   (l) Disturbance of balance/coordination………………….…….………Yes No
   (m) Numbness in hands or feet……………………………………….….. Yes No
   (n) Disturbance of vision……………………………………….……..... Yes No
   (o) Thyroid problems…………………………………………….………. Yes No
   (p) Kidney or liver problems…………………………………………….. Yes No
   (q) Allergy to nuts…………………………………………………..……. Yes No
   (r) Allergy to sticking plaster……………………………………........ Yes No
   (s) Ear/hearing problems…………………………………..……… Yes No
   (t) Problems clearing your ears when flying………………………..... Yes No

4. **Do you:**

(a) feel pain in your chest at rest or when you do physical activity?... Yes No

(b) lose your balance because of dizziness or ever lose consciousness?...Yes No

(c) have a bone or joint problems that could be made worse by a change in physical activity?...Yes No

(d) know of any other reason why you should not do physical activity?...……….Yes No

5. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?...Yes No

6. **At present,** are you pregnant or do you believe that you may be pregnant?...………………Yes No

If you have answered YES to any question, briefly give details below if you wish (was the problem short term, insignificant and/or well controlled?)

Thank you

Volunteer signature……………………………….. Date……………..

Medical Officer signature……………….……….. Date………………

Appendix 6

RAF CENTRE OF AVIATION MEDICINE
AIRCREW CONDITIONING PROGRAMME STUDY - WEEKLY LOG UPDATE

Participant number: _______ Date completed:_______

Total number of flight hours this week: _______

Total number of hours flown with NVG/HMD this week: _______

Total number of BFM/ACM flight sorties this week: _______

1. Did you exercise this week? Yes [ ] No [ ]
   If No, give the details and reasons why:

   If Yes, check the box indicating how many hours you did the supervised **Aircrew Conditioning Programme**:

1-2	3-5	6-7	8-10	11-13	14	Not Applicable
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Check the box indicating how many hours you did additional **aerobic exercise**:

1-2	3-5	6-7	8-10	11-13	14	Not Applicable
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Check the box indicating how many hours you did additional **anaerobic exercise**:

1-2	3-5	6-7	8-10	11-13	14	Not Applicable
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Check the box indicating how many hours you did additional **weight lifting**:

1-2	3-5	6-7	8-10	11-13	14	Not Applicable
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

2. Did you experience neck ache / pain /strain **related** to flying this week? Yes [ ] No [ ]
   If yes, list the number of neck pain episodes you experienced: [ ]
   If yes, on average, check the box indicating how long the pain persisted:

0-1 hr	1-2 hr	2-4 hr	4-8 hr	8-12 hr	12-24 hr	24-36 hr	36-48 hr	More than 48 hr
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Rate the average flying-related pain severity by checking the box along this line:

0 (No Pain)	1	2	3	4	5	6	7	8	9	10 (Maximum Pain)
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Rate the worst flying-related pain severity by checking the box along this line:

0 (No Pain)	1	2	3	4	5	6	7	8	9	10 (Maximum Pain)
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

3. Did you experience neck ache / pain /strain **unrelated** to flying this week? Yes [ ] No [ ]

If yes, describe the cause and the symptoms experienced:

If yes, list the number of neck pain episodes you experienced: [ ]

If yes, on average, check the box indicating how long did the pain persisted:

0-1 hr	1-2 hr	2-4 hr	4-8 hr	8-12 hr	12-24 hr	24-36 hr	36-48 hr	More than 48 hr
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Rate the average non-flying-related pain severity by checking the box along this line:

0 (No Pain)	1	2	3	4	5	6	7	8	9	10 (Maximum Pain)
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Rate the worst non-flying-related pain severity by checking the box along this line:

0 (No Pain)	1	2	3	4	5	6	7	8	9	10 (Maximum Pain)
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

4. If you answered **Yes** to Question 2 or 3;

Did you have any treatment for your neck pain this week? Yes [ ] No [ ]

If yes, check the box indicating how many times:

1	2	3	4	More than 5
[ ]	[ ]	[ ]	[ ]	[ ]

5. Where did you seek treatment? (more than one may be selected):

[ ] Sick Parade/SMO
[ ] Physiotherapist **on** Station
[ ] Physiotherapist **off** Station
[ ] Chiropractor
[ ] Osteopath
[ ] NHS GP
[ ] Self-medication
[ ] Pharmacist
[ ] Other (please specify) __________________